



BANK OF CANADA

Price Adjustment and Monetary Policy

Proceedings of a conference
held by the Bank of Canada

November 2002

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Introduction

Don Coletti

The focus of the 2002 Bank of Canada conference was price adjustment and its implications for monetary policy. Rather than pursuing a specific policy question, its aim was to take stock of the current state of knowledge on a critically important issue for monetary policy.

Although voluminous research has developed on the issue of what determines aggregate price adjustment, interest from the academic community has ebbed and flowed. The early rational-expectations literature and real-business-cycle models of the 1970s and 1980s did not include a role for sticky prices and thus downplayed the importance of monetary policy. In the macroeconomics literature of the 1990s and 2000s, in contrast, there has been general acceptance of the existence of price stickiness in goods or labour markets, or both, and of the important role that monetary policy can play in an economy. The timing was therefore appropriate for a conference that would focus on current developments in this area of research, particularly within a Canadian context.

The conference consisted of a memorial lecture, five sessions of one or two presentations each, and a closing panel discussion. Designated discussants commented on each session, and questions were taken from the floor. Pierre Duguay, Deputy Governor of the Bank of Canada, Gregor Smith of Queen's University, and Michael Woodford of Princeton University were the distinguished members of the closing panel. Papers ranging from surveys of recent literature to empirical studies and theoretical treatments explored several important themes: alternative sources of inflation persistence; estimating forward-looking models of inflation; the complex issues surrounding price adjustment in an open economy, including movements in the exchange rate, and their effect on economic behaviour;

the interaction between wage adjustment, price inflation, and real economic outcomes; and the macroeconomic effects of technology shocks.

Session 1: Empirical Models of Price Adjustment

The so-called New Keynesian Phillips curve (NKPC) is an approach to understanding price dynamics that incorporates sticky prices into profit-maximizing models of firm behaviour in which firms form expectations rationally. In the benchmark NKPC, current inflation depends solely on future expected inflation and the real marginal cost of production (the ratio of marginal cost to price) or detrended output. It thus provides no explicit link between current and past inflation, which has two related implications. First, since lagged inflation plays no role, the persistence of inflation will be determined solely by the persistence of real marginal cost, a result that is usually insufficient to explain inflation persistence. Second, the absence of lagged inflation means that inflation will respond very quickly to new developments, so that costless, or even beneficial, disinflations are possible. This result is inconsistent with historical disinflation episodes.

Sharon Kozicki and **Peter Tinsley** examine four variants of the benchmark NKPC that are designed to improve the model's ability to account for the observed persistence of inflation in Canada and the United States. The first extension relaxes the assumption of rational expectations. More specifically, some studies (e.g., Roberts 1997, 2001 and Gali and Gertler 1999) have assumed that a fraction of agents use a simple autoregressive structure to forecast inflation. Assuming this alternative form for inflation expectations is one way to rationalize the inclusion of lags of inflation in the benchmark NKPC. A second alternative is to introduce staggered contracting specifications, using an extension of Taylor's (1980) framework to obtain more complicated lag dynamics. A third approach considers costs of adjusting prices, inflation, and potentially, changes in inflation. This extension also admits additional lags of inflation into the Phillips curve. The final extension allows for a non-zero "perceived target" for inflation that could evolve as an additional source of inflation stickiness.

The authors conclude that although shifts in long-run anchors of agent expectations contribute "importantly to observed persistence in U.S. and Canadian inflation," they are clearly not the only source. Models that admit additional lags and leads of inflation, such as the staggered-contract model, are clearly able to explain inflation better than purely forward-looking specifications, even after accounting for shifts in the perceived target. Discussant **Michel Normandin** cautioned that the econometric tests employed were not very powerful for discriminating among the various

specifications and that the results may be sensitive to the selection of measures of inflation and the method used to detrend output.

Alain Guay, Richard Luger, and Zhenhua Zhu study the sensitivity of previous NKPC estimates to various econometric assumptions. Using Canadian data from 1970 to 2000, they find that previous NKPC estimates are sensitive to different assumptions. They propose an approach to estimation that has three advantages: (i) the asymptotic bias of the coefficient estimates does not increase with the number of instruments; (ii) an analytical method can be adopted for correcting the bias in the estimates of the structural parameters in a non-linear model; and (iii) the estimates are invariant to the normalization of the orthogonality condition. The authors also extend the standard NKPC to the case of an open economy and examine various measures of real marginal cost. The results suggest that none of the NKPC specifications tested in the paper are supported by the data. Discussant **Jean Boivin** presented some reduced-form Phillips curves that suggest a statistically significant relationship between real marginal costs and inflation. He suggested that richer specifications of the NKPC model than those examined in the paper need to be considered before the NKPC model can be rejected.

Session 2: The Labour Market and Price Adjustment

A well-known fact about labour markets in the United States is that employment is much more variable than real wages. **Michelle Alexopoulos** examines the inability of standard limited-participation models to address this issue without relying on unrealistically high elasticities of labour supply with respect to real wages and high price markups over marginal costs. The author embeds an efficiency wage model in a standard limited-participation model with the twist that, instead of firing workers who are shirking, firms simply do not pay them their quarterly bonus. This feature significantly improves the model's ability to explain the relative variability of employment and real wages. In his discussion, **Scott Hendry** proposed numerous extensions, including the addition of labour market search to the efficiency wages in this model. With both frictions in the same model, it would be possible to estimate the relative contributions of search and efficiency wages to the determination of employment and the real wage.

Robert Fay and Sebastien Lavoie seek to establish a relationship between the duration of labour contracts and uncertainty (both uncertainty about the real economy and uncertainty about inflation) using data on Canadian wage settlements from 1978 to 2001. The literature suggests that falling inflation uncertainty should be associated with lengthier labour contracts. The results from the estimation of a simultaneous equation probit model confirm

previous findings of such a negative relationship between inflation uncertainty and contract duration. The empirical findings, however, do not corroborate theoretical research that suggests that uncertainty about the real economy plays an important role. The discussant, **John Knowles**, suggested that an explicit accounting for the prevalence of non-indexed contracts is needed before it can be concluded that longer labour contracts in Canada are the result of reduced uncertainty about inflation.

Session 3: Price Adjustment and Monetary Policy

Gali (1999) presents an empirical challenge to the real-business-cycle literature and modelling strategy. Using assumptions similar to those in Blanchard and Quah (1989), he finds that the hours-worked variable initially falls following a positive technology shock and only eventually rises, while the prototypical real-business-cycle model implies that this variable should rise immediately after such a shock. Gali suggests that this decline in hours worked is consistent with the predictions of macroeconomic models that feature nominal rigidities.

Christiano, Eichenbaum, and Vigfusson argue that Gali's empirical findings are fragile. Their empirical re-examination finds that a permanent positive shock to technology leads to a rise in the number of hours worked as well as rises in output, average productivity, investment, and consumption, and a fall in inflation. The difference in results can be attributed to the underlying statistical model of per-capita hours worked. The authors assume that hours worked is mean-reverting, whereas the previous literature assumed that only the change in hours worked is mean-reverting. They use statistical tests to argue that the preponderance of evidence supports their conclusion.

The authors also show that although the technology shocks they identify have qualitatively similar effects to those implied by the real-business-cycle model, these shocks explain only a fraction of overall volatility at a business cycle frequency. For example, these shocks are responsible for 10 per cent of the cyclical variation in output, but account for 23 per cent of the cyclical variation in inflation. Technology shocks play a much more important role in determining the low-frequency component of aggregate fluctuations.

Discussant **Kevin Moran** suggested that alternative artificial data sets be used in experiments that test the ability of each of these empirical specifications to recognize the alternative possibility. First, a standard real-business-cycle model that generates a positive correlation between hours worked and technology shocks could be used to generate data. Gali's difference-stationary specification could then be applied to these data to test whether it

recognized the alternative possibility. A similar experiment could be run with a sticky-price model (which generates a negative correlation between technology shocks and hours worked) and subsequently tested with the level specification.

In his discussion, **Martin Gervais** focused on the finding that technology shocks account for very little of the cyclical variation in output. He contrasts this result to earlier work by Prescott (1986) and Aiyagari (1994), which concluded that technology shocks accounted for about 75 per cent of the fluctuations in real output in the post-war period, and concludes that the discrepancy results from differing definitions of a technology shock. Prescott and Aiyagari broadly referred to technology shocks as any shock that directly affects the production frontier, while Galí and the authors limit their discussion to permanent productivity shocks.

Session 4: Small Open-Economy Models

In recent years, considerable research has been devoted to New Keynesian, open-economy models, that is, multi-country dynamic general-equilibrium models with nominal price rigidities, optimizing agents, and stochastic shocks that permit welfare analysis. **David Bowman** and **Brian Doyle** present a survey of this growing area of literature. They review the original Redux model (Obstfeld and Rogoff 1995), its implications, and some of its extensions, specifically those considered qualitatively most important for understanding optimal monetary policy. Static extensions they consider include different preferences for domestic and foreign goods, pass-through from exchange rates to domestic prices, and wage stickiness versus price stickiness. Discussion of dynamic extensions includes stochastic shocks, asset markets, and current-account dynamics. The authors then explore the implications of producer-currency pricing and incomplete pass-through for optimal monetary policy in a single country, as well as the issue of international policy coordination. They conclude that more gains have been made in conceptual insights, such as understanding the transmission of shocks across countries, exchange rate pass-through, and the effects of different pricing rules, as well as how these affect optimal monetary policy rules and international policy coordination, than in providing empirical verification.

Frank Smets, the discussant, noted that this class of model typically has very little new to say about the determination of exchange rates. He pointed to recent developments in the literature that could lead to an improvement in the model's ability to capture and explain movements in exchange rates. In particular, he suggested incorporating transportation and distribution costs that drive a wedge between movements in exchange rates and the

fundamentals in the economy (Corsetti and Dedola 2002). He also cited the need for additional research with stochastic models to better understand how risk premiums interact with the macroeconomy (Obstfeld and Rogoff 1998).

Session 5: Price-Setting in a Small Open Economy

Gabriel Srou begins his paper by analyzing monetary policy in a simple, single-period model of a small open economy with nominal-wage rigidities and decreasing returns-to-scale technology. The model's goal is to examine the efficiency of monetary policy in various environments on the basis of its ability to reproduce the flexible-price equilibrium.

The alternative cases include: (i) a baseline one-sector model with one domestically produced good and one foreign-produced good, where all prices are set in the world market; (ii) a baseline model to which fixed costs of production (a measure of a firm's degree of efficiency) are added, as in Blanchard and Kiyotaki (1987); and (iii) a two-sector model composed of primary goods whose prices are set exogenously in the world market, and traded manufactured goods (which have a higher elasticity of substitution with foreign manufactured goods than with primary goods). In the two-sector model, the author examines the two extreme assumptions regarding labour mobility between the sectors, i.e., perfect and none, as well as the two cases where prices of non-primary goods are set in the world market and where they adjust endogenously.

Srou finds that, in one-sector models, monetary policy can reproduce the flexible-price outcome where there are no fixed costs but not always in the model with fixed costs. In the two-sector model, it can reproduce the flexible-price outcome as long as labour is mobile. Monetary policy is unable to replicate the flexible-price equilibrium when labour is immobile across sectors because it cannot achieve potentially conflicting goals in two separate labour markets with only one instrument. The discussant, **Craig Burnside**, suggested extending the model to allow for a less stark analysis of the impact of labour mobility. This adaptation could lead to an empirical assessment of the issues Srou raises.

Michael Devereux and **James Yetman** address the issue of exchange rate pass-through. An extensive literature covering a range of industrialized and developing countries has documented incomplete pass-through of exchange rates to consumer prices, even in the long run. Recently, considerable debate, fuelled in part by the widespread belief that pass-through may have declined in the 1990s, has focused on the causes of this incomplete pass-through. Some explanations include pricing to market by imperfectly competitive firms (Corsetti and Dedola 2002) and domestic

content in the distribution of traded goods (Corsetti and Dedola 2002; Burstein, Neves, and Rebelo 2000).¹

The authors develop a simple model of a small open economy in which exchange rate pass-through is determined by the frequency with which importing firms change their prices. These firms choose how often to change prices in response to exogenous shocks, comparing the costs of making a price change to the losses associated with not changing their prices (a decline in the relative price). A higher mean inflation rate leads to larger losses from holding prices constant, and is therefore associated with more frequent price changes and a higher degree of exchange rate pass-through. This model implies that there should be a positive, but non-linear, relationship between mean inflation and pass-through, and a positive relationship between exchange rate volatility and pass-through. The authors find evidence of this in their sample of 122 countries. Their results suggest that sticky prices are an important factor in determining the average rate of pass-through and that a low rate of pass-through results at least partly from short-term price rigidities.

Beverly Lapham, in her discussion, focused on the need for a better understanding of price-setting behaviour so that researchers can use measures of exchange rate pass-through that control for other factors affecting prices. She also called for additional studies at higher levels of industry disaggregation and at various stages of production and distribution. The second discussant, **Jeannine Bailliu**, commented on the policy implications for emerging markets. She suggested that this paper could provide some theoretical and empirical support for the largely anecdotal evidence from some emerging markets that a large reduction in the degree of exchange rate pass-through had accompanied the significant reduction in their inflation rates in the 1990s.

Panel Discussion

The panellists provided thought-provoking commentary and interesting suggestions for future research. **Gregor Smith** focused his comments on econometric issues, noting in particular that single-equation methods and aggregate macroeconomic data may not provide enough information to answer many of the questions about price adjustment. He cited the Fay and Lavoie study as an excellent example of combining information sources. Smith also suggested that industry-level models or models with a strategic element may be useful in characterizing price adjustment. In particular, he

1. In a similar vein, Taylor (2000) examines links between monetary policy and pass-through of cost changes to prices.

highlighted the importance of paying attention to the cross-sectional dimension of industry-level data.

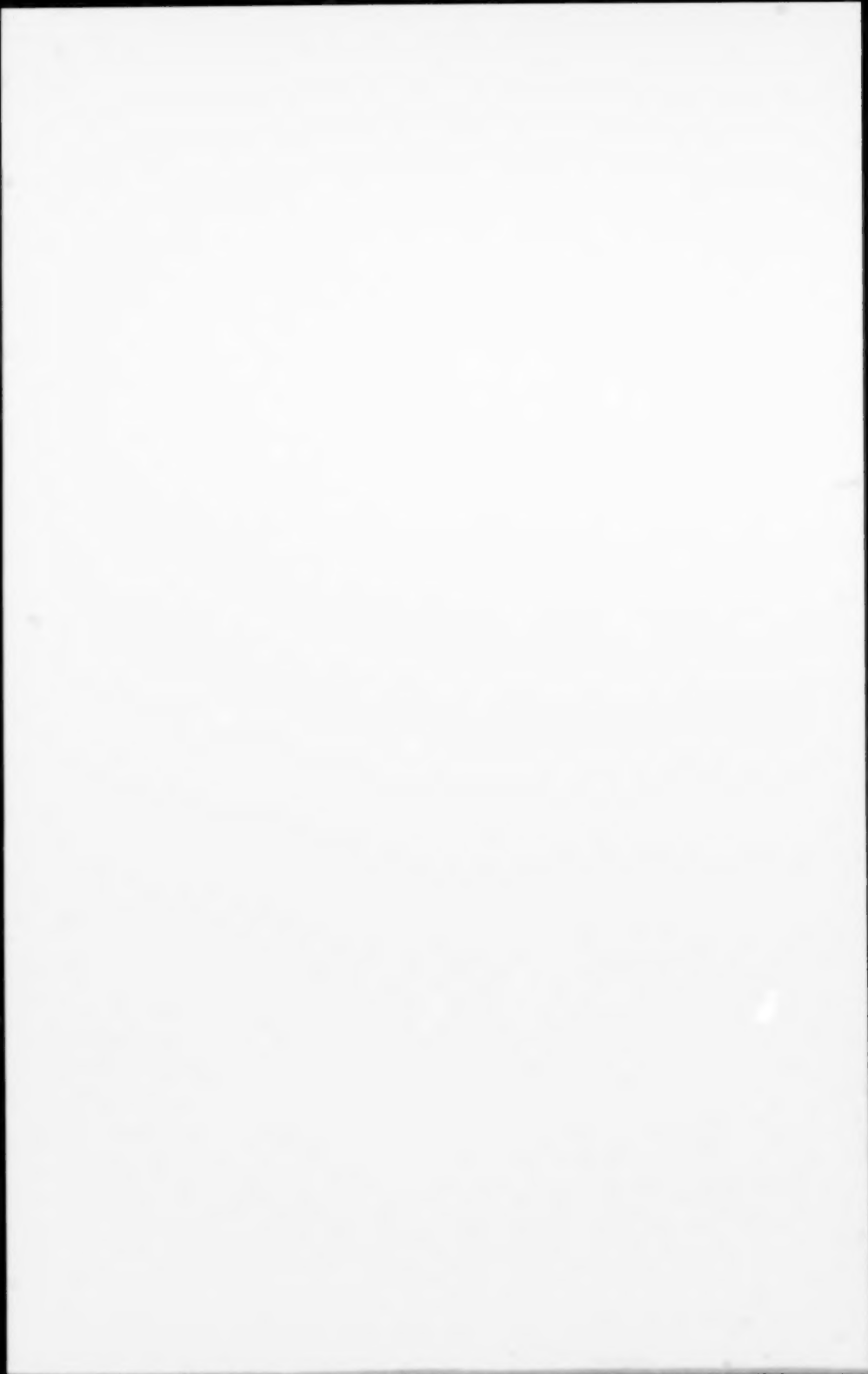
Michael Woodford focused on the importance to monetary policy of structural models for determining wages and prices. He compared alternative models of the aggregate-supply relationship on the basis of the degree of inflation inertia that they imply, specifically, models of the hybrid NKPC with differing degrees of indexation. He showed that the degree of inflation inertia has important consequences for determining the appropriate stabilization objectives of monetary policy, the optimal long-run inflation target, the degree to which temporary departures from the long-run target should be allowed, and the form of the optimal targeting rule. He concluded by calling for further research on the question of whether inflation inertia should be regarded as truly structural.

Pierre Duguay thanked the participants for their excellent contributions. He agreed with Beverly Lapham's suggestion that more work is required to understand the pricing strategy of firms. He announced that the Bank of Canada would be undertaking a survey of firms, much in the spirit of Blinder et al. (1998), and would be directly asking real-world price-setters how prices are set. This work is currently underway and is expected to be completed in 2003. He expressed reservations about the applicability of the NKPC model of inflation to the Canadian GDP deflator, which is heavily influenced by movements in world commodity prices. He also encouraged researchers to allow for changes in the monetary policy regime in their empirical analysis of the inflation process.

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Opening Remarks

Tiff Macklem

It is my great pleasure to welcome you to the Bank of Canada and to introduce our conference, *Price Adjustment and Monetary Policy*. Many of you have participated in previous Bank conferences, and we have greatly appreciated the creative ideas, careful research, and thoughtful insights you have brought over the years. We are very pleased to have you back. I want to particularly welcome those of you who are here for the first time. I hope your visit is a good one and that this is the beginning of a long and fruitful relationship.

I thought that I would first say a few words about what we had in mind when we drew up the agenda, and what we hope to derive from the conference.

The Bank of Canada has held an economic conference every year since 1990. These conferences are very important for us. They serve to present the results of our research to experts at the cutting edge of their fields, and to make known new ideas, new techniques, and new findings. A number of the previous conferences were concerned with specific policy issues, such as the comparative merits of fixed and floating exchange rate regimes and the design of the inflation-control framework.

This conference is a little different. The agenda is not focused on a specific theme. Its objective, rather, is to improve our understanding of the economy as a whole, particularly from the standpoint of price adjustment and monetary policy. We were led to take this approach for three reasons.

First, the profession is once again returning to sluggish adjustment of wages and prices as an important source of macrodynamics. But following on rational expectations and real-business-cycle theory, this return has devoted much more attention to optimizing theory, and this has the potential to yield important new insights.

Second, richer theory is accompanied by new econometric techniques designed to exploit the restrictions imposed by theory and to improve estimation and inference in models with unobserved expectational variables. This combination has the potential to improve our empirical understanding of the macroeconomy.

Third, when we look out the window, we see a number of developments that may be important from a monetary policy perspective. Canada has long been a very open economy, and with the Free Trade Agreement and subsequently NAFTA, our economy has opened further to trade. In the 1990s and 2000s, we have seen a decline in the volatility of most macro variables, exchange rate pass-through appears to have slowed, the average duration of labour and debt contracts has increased, and trend productivity growth appears to have risen. What do these developments mean for price adjustment and monetary policy? What can we learn from theory? And what does careful empirical work tell us?

We are very pleased to have with us today such a distinguished group of authors and discussants who will be examining these questions from various perspectives. I strongly encourage you to put our speakers to the test and provide us with material for reflection during the discussion periods. The authors' papers, the discussants' comments, and the general discussions will all be published in the conference proceedings.

So I thank you for being here. We have before us a very stimulating agenda that I am sure will leave its mark on our ideas, our understanding of the economy, our models, and our future research.

Before I turn over the floor, my final responsibility is to introduce our first speaker, Bill Searth. As pleased as I am to do so, this lecture marks a very sad occasion. In January 2002, our colleague, John Kuszczak, passed away after a courageous two-year battle with cancer. Many of us were lucky enough to work with John over his 20-year career at the Bank. I know I speak for all of us when I say we miss him. I particularly miss dropping by John's office to get his thoughts on whatever was puzzling me. John always had time for you if you wanted to bounce something off him, economics or otherwise. He did not always know the answer, but he always knew what was not the answer. He was very careful about the details, but when he did give you a response it was usually remarkably simple. John had a great sense of what's important and what isn't—that's a valuable skill in an economist. It is also valuable in a friend.

This is the first in what will be an annual Memorial Lecture in memory of John Kuszczak's many contributions to the Bank and to his colleagues. I am very pleased that Bill Scarth accepted our invitation to deliver the first John Kuszczak Memorial Lecture.

Bill is well known to most of us. After doing a Ph.D. in economics at the University of Toronto, he began teaching at McMaster University where he is a full professor. Bill has contributed numerous scholarly papers to academic journals, books, and conference volumes on a wide range of macro topics, including fiscal and monetary policies, labour market issues, and inequality and growth. Bill is also recognized as a masterful teacher. Winner of the lifetime achievement award in teaching at McMaster, he has also written the Canadian versions of principles textbooks with Allan Blinder and William Baumol and with Gregory Mankiw. We at the Bank have particularly appreciated Bill's long-time interest in and prolific contributions to policy issues as an Adjunct Scholar to the C.D. Howe Institute and as a frequent contributor to conferences here at the Bank and at many other policy institutions and organizations.

Bill is uniquely qualified to deliver the first John Kuszczak Memorial Lecture. As a young professor at McMaster, Bill recognized John's talent and was a mentor and eventually thesis adviser for John in graduate school. John and Bill kept in touch until John died. Bill, I know you had a big influence on John.



Memorial Lecture: Contributions of John Kuszczak

William Scarth

I am grateful for this opportunity to share some of my recollections about John Kuszczak. The Bank is to be commended for dedicating this year's conference to John's memory, and for arranging an ongoing tribute in the form of the John Kuszczak memorial lectures that will be part of future annual conferences.

I deeply value my association with John. At the personal level, he epitomized the balance that I admire. As John's Ph.D. supervisor, I witnessed first-hand his tireless commitment to thorough and rigorous analysis. He avoided simplifying assumptions that would advance a study if he felt that, by invoking these assumptions, the applicability of the research might be compromised. It takes a person with a deep sense of peace to be truly comfortable with the adage "virtue is its own reward." John had that inner calm. By being a perfectionist, he missed out on some of the perks that others enjoy—such as receiving a Ph.D. John did not submit a thesis, since he felt that his work was not "significant enough." I disagreed and feared that his decision might hurt his career. Happily, my concern was unnecessary, since John's colleagues here at the Bank were quite capable of appreciating John's worth. But my point is that, before John knew his career would not suffer, he still made the choice to risk that cost. For John, it was more important to focus on core issues, high standards, and friends. He was satisfied when he met his own goals; he was not distracted by a need for external recognition. This quiet self-confidence is what made John such a perfect colleague. With his own inner peace, concern about recognition never impeded his generosity and supportive nature. Thus, both personally and professionally, John was an inspiration.

Before I comment on some of John's work, I would like to tell you a little more about his experience as a graduate student. You are, of course, aware of John's organizing the season's tickets here in Ottawa for Senators' games. John displayed the same interest in hockey back at McMaster. Indeed, he stood out in our annual hockey playoff pool. Ours was tailor-made for economists. Each participant was given \$100 of play "money," and then 128 NHL players were auctioned off in random order. The participant whose players scored the most points by the end of the playoffs won the pot of real money. Participants could opt for many different strategies—from having a long list of cheaply priced, less skilled players to having a short list of expensive, particularly gifted players. The contest required exceptional forecasting ability: which teams were likely to play in many series? which players would better avoid the tighter checking in the playoffs? and so on. Participants could not prepare a set of what they judged to be a maximum sensible price for each player in advance, since without prior knowledge of the number of participants, they did not know the aggregate money supply until the last minute. John won this pool several times. Eventually, other players figured out a new strategy; they decided to outbid John for every player he expressed interest in. John was not able to revise his strategy quickly enough during the auction and so he did terribly that year. The auction ended with John having bought almost no players. I have wondered whether that is why John went to the Bank of Canada. After all, that experience in the hockey pool had identified a gap in his skills. While he excelled when he was a price-taker, he did not when he was a price-maker. Perhaps John was determined to repair this deficiency, and what better way to do so than by going to work for—and therefore to learn from—the institution that is a price-maker in important financial markets. People at the Bank quickly realized John's forecasting skills could be transferred from hockey to macroeconomics. One of his contributions over the years here at the Bank was in this very area.

I enjoyed discussing monetary economics with John when he was at McMaster. The paradigm of the day was the first generation of rational-expectations models—involving descriptive structural equations (each with some micro-foundations but provided only on an equation-by-equation basis). One particular application of the Lucas critique captured John's attention. Central banks were shifting from a strategy of interest rate smoothing to one of monetary aggregate targeting, and macroeconomists were exploring the implications of this change in policy regime for output and price volatility. John felt that the linearity of these models suppressed an important issue. Standard portfolio theory (*à la* Tobin) leads to the proposition that the interest elasticity of money demand is a function of the variance of the interest rate. This dependence was ignored in the literature,

and John wanted to highlight this effect, since he thought it was central. After all, the regime change to money supply targeting was certainly raising the observed interest rate volatility. But the execution of this task was difficult, since it involved using the solution equation for interest rate variance to determine the size of one of the model's slope coefficients. John was wrestling with how to make this connection in a tractable way, when a working paper authored by a young assistant professor from Princeton appeared. Carl Walsh's paper entitled "Interest Rate Volatility and Monetary Policy" had answered this challenge in a particular way, and this paper later appeared in a 1984 volume of the *Journal of Money, Credit and Banking*. John felt that the existence of Walsh's paper had lowered the importance of his own work.

Was it sensible for John to withdraw from this particular line of research so quickly? The fact that there have been relatively few related papers suggests that many macroeconomists have implicitly responded to this question in the affirmative. Nevertheless, there have been other studies on this topic (for example, McCafferty and Driskill 1980a; Eaton and Turnovsky 1983; and Turnovsky 1989, 1995), and I think that it is worth briefly reviewing this work.

One issue is that tractability challenges are an even larger concern within the current generation of macro-models. In the modern approach, micro-foundations for the *entire set* of structural equations are derived from one integrated intertemporal optimization. In this more structured framework, it is even more difficult to derive closed-form solutions that allow slope coefficients to depend on the variances of endogenous variables. These issues are avoided when researchers such as McCallum and Nelson (1999), in their paper on an optimization-based IS curve, follow the standard practice of taking a linear approximation of the household Euler condition. This excludes the covariance terms that are necessary to highlight the effects of risk aversion.

Another consideration is that we almost always assume that agents have access to bonds that mature in one period (so there is no uncertainty about the holding-period yield on bonds). Walsh makes clear that his analysis collapses if it is not assumed that the term to maturity of the bond does not exceed one period. More generally, Walsh is forced to simplify in other ways. For example, he assumes that individuals know the value of all current disturbances before making their portfolio-allocation decision. He regards this assumption about information structure as a "compromise." He is uncomfortable with allowing agents this much access to current information, but he feels that this assumption is nevertheless acceptable, since it makes relatively simple solutions possible. I recommend a tolerant

attitude on such matters, since—whether it is often appreciated or not—standard results in much simpler settings often depend on rather unappealing assumptions concerning information availability. For example, in the original “policy relevance” paper by Sargent and Wallace (1976), that startling conclusion does not follow if the information available to agents when deciding how much to spend is the same as what is now usually assumed (for example, in McCallum and Nelson’s paper). It is also the case that if the McCallum and Nelson analysis is reworked with the information-availability assumption used by Sargent and Wallace, the entire solution procedure breaks down. The identifying conditions involved in the undetermined coefficient solution method impose restrictions on some of the structural—not reduced-form—parameters. As noted, therefore, a tolerance for convenient assumptions regarding information availability appears to be already implicitly involved in modern macroeconomics.

Turnovsky (1995, chapters 14 and 15) keeps his analysis from depending on arbitrary differences in discrete timing by working in a continuous-time setting. He studies an endogenous growth model with infinitely lived agents who intertemporally optimize in a system of stochastic differential equations. He notes that this continuous-time approach is not common, because such specifications are tractable only when strong assumptions are made. But Turnovsky argues that when these simplifying conditions are imposed, the solutions turn out to be “highly transparent,” and the analysis then provides substantial intuitive understanding. Turnovsky applies this approach to tax policy and growth. One result bears directly on the methodological issue that intrigued John as a graduate student.

A standard result in endogenous growth theory is that a tax on the earnings of capital lowers the growth rate. But in Turnovsky’s analysis, there are competing effects. On the one hand, the tax reduces the after-tax return on capital, and this is growth-decreasing. On the other hand, the tax reduces the variance of that return, and this induces savers to hold a higher proportion of their portfolios in capital. This latter effect is growth-increasing. Turnovsky’s formal integration of macroeconomic growth equilibrium and finance theory is not the first to stress the possibility that higher taxes on capital can stimulate growth. Nevertheless, he has demonstrated this possibility in precisely the setting (stochastic intertemporal optimization) that is now regarded as the proper basis for analysis of business cycles. Since inflation interacting with a non-indexed tax system is like a tax on capital, I take Turnovsky’s analysis as an indication that it may be worthwhile to examine similar models that focus on monetary policy issues. (Turnovsky reports some progress on this agenda in the second edition (2000) of his book.) It appears that we may now be better equipped to follow up on John Kuszczak’s interest in giving the assumption of risk aversion a

more central role in monetary policy analysis. The Walsh and Turnovsky analyses suggest that there may be a significant payoff in pursuing this topic, thereby proving that John may have been too quick to set his thesis topic to one side.

Of course, we should not presume that this work will lead to major changes in policy conclusions. When I insert what I regard as plausible parameter values into the inequality that must hold for Turnovsky's analysis to support the proposition that a higher capital tax raises growth, I conclude that there is no way that this condition is satisfied. Nevertheless, we now have the software (thanks to Gaspar and Judd 1997) to pursue models of this sort that are much less stylized, so Turnovsky's analysis should be interpreted as a template for further work.

It is also worth noting that Gaspar and Judd are not the only ones to explore the implications of second-order Taylor expansions. Campbell and Viceira's (1999) partial-equilibrium model involves the simultaneous derivation of optimal consumption over time and portfolio allocation. They conclude that the intertemporal hedging that becomes a feature of their analysis has a quantitatively important effect on portfolio choice. In related work, Wolman and Couper (2003) update McCafferty and Driskill (1980b) and highlight another risk that follows from taking linear approximations—that, even in very simple macro models, this standard practice can lead to erroneous results about the existence and uniqueness of equilibrium.

I am pleased that some of the research presented at this conference stresses open-economy aspects of risk aversion. In Devereux and Yetman's (2003) menu-cost model of endogenous price stickiness, a higher variance of the nominal exchange rate leads to a more volatile marginal cost schedule for firms. The result is that firms find it profitable to incur the menu cost more frequently, so prices are less sticky and the degree of exchange rate pass-through is higher. Since a more aggressive inflation-targeting policy on the part of the central bank limits exchange rate volatility, monetary policy affects a number of slope coefficients (such as the slope of the short-run Phillips curve and the degree of exchange rate pass-through). This set of results is an open-economy analogue of what interested both John Kuszczak and Carl Walsh years ago. In this instance, it is the variance of the exchange rate affecting key supply-side slope parameters, instead of the interest rate variance affecting demand-side slope parameters.

In another paper at this conference, Bowman and Doyle (2003) explain the implications of introducing stochastic shocks into what is now the core model for international macroeconomics. As in the earlier work noted above, simplifying assumptions (such as a unitary elasticity of substitution in consumption between domestically produced and foreign goods) keep the

analysis tractable. Bowman and Doyle direct our attention to several recent papers that show how the variance of some of the variables affects the mean values of other endogenous variables. Since this is precisely the feature that John Kuszczak regarded as important if a macro model is to be useful for studying monetary policy, I am pleased that this aspect of modern work is being highlighted here.

While I have emphasized the payoff that appears to accompany further study of the macroeconomic implications of risk aversion, I do not wish to leave the impression that I resist the development of the "new neoclassical synthesis" model. I think we have made fundamental progress when both new classicals and New Keynesians embrace a compact structure that has appealing intertemporal optimization underpinnings and that can be discussed at the same aggregation level as older-generation, policy-oriented models. Bob King (2000) has reminded us that the new compact framework should be questioned to determine under what conditions the equations are truly structural. Thus, we must continue to explore how the properties of the core model are affected by sensitivity tests such as the one John and others I have just mentioned have pursued.

Since time does not permit doing justice to John's contributions at the Bank, I will mention just a few. The 1994 conference here at the Bank included a paper (Kuszczak and Orcheson 1995) that investigated the existence of differences across firms in their responses to changes in monetary conditions. John and Peter considered firm size and different industrial sectors. One indicator was the slope of the yield curve.

When rereading this study, I couldn't help relating it to one of the Turnovsky papers (1989). That analysis of the yield curve allows for risk aversion, so the parameter in the standard asset-pricing relationship depends (as it should, according to portfolio theory) on the variance of the long-term interest rate. This model does not involve the "new" expectational IS relationship. Nevertheless, it is straightforward to show that the term-structure equation and the old-fashioned IS function involving the long rate (that is part of Turnovsky's model) can be combined to yield the new expectational IS function involving the short rate.

One of Turnovsky's results is that unanticipated permanent fiscal changes initially affect the long rate more than the short rate. Such results help explain the observed volatility in long rates, and they suggest caution when interpreting the slope of the yield curve as a monetary policy indicator.

The breadth of John's work can be illustrated by just a few other references. With John Murray (Kuszczak and Murray 1987), he completed a valuable VAR study on the interdependence of the Canadian and American

economies—that tested for differences across the fixed and flexible exchange rate periods. Five years ago (Kuszczak and Dion 1997–1998), John turned his attention to such things as the aging population as he prepared predictions of potential GDP. Changing research topics once again, in association with others who presented their work at last year's workshop (Côté et al. 2002), John critically reviewed all the applied macro-econometric models of Canada.

In addition to these publications, John provided much-appreciated guidance to some of the former Soviet republics as they were designing new central banks. It is particularly significant that John was the first at the Bank to recommend zero chartered bank reserves. His well-reasoned study (Kuszczak 1986) gave equal attention to second-best public-finance issues and to macro-stability concerns. When this study was circulated, I gather it was regarded as almost revolutionary. But John's analysis stood the tests of time and scrutiny, and as we all know, his conclusion was later adopted as the new policy.

Even if I had more time to describe all the projects that John worked on, I would not be stressing what needs to be said most. John's most important contribution was in his role as wise counsellor—helping everyone else sort out their problems and perspective. I last talked to John at a previous Bank conference. He would not let our conversation shift to a discussion of his health. He was much more comfortable exploring the issues that had emerged in the day's discussions—helping me to understand and enjoy economics. His insights and his spirit continue to help me.

The word "gentleman" was invented for people like John. He was a truly gentle man who—by simply pursuing his work in a careful and unassuming fashion—generated the many positive externalities and inspiration that we are celebrating by dedicating this conference to him.

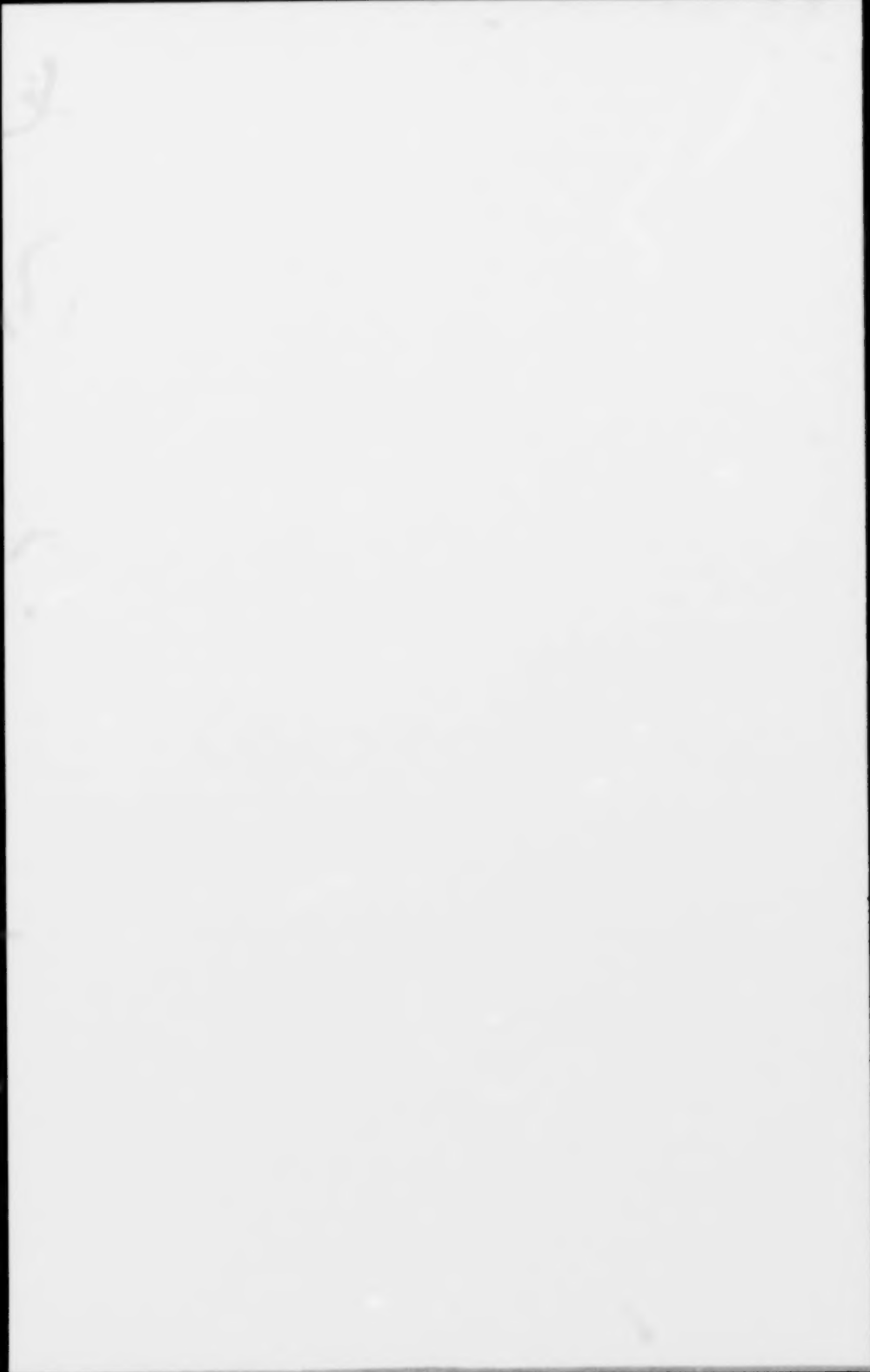
Thank you for letting me take part in this tribute.

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Section 1: Empirical Models of Price Adjustment



Alternative Sources of the Lag Dynamics of Inflation

*Sharon Kozicki and Peter A. Tinsley**

Introduction

New Keynesian Phillips curves are widely used in macroeconomic policy models to simulate the inflation consequences of alternative monetary policies. The purely forward-looking inflation specification is appealing, because it is based on a model of optimal pricing behaviour. However, based on empirical evidence, the standard view is that there is considerable persistence in inflation. Consequently, the purely forward-looking specification is controversial, because it excludes lagged inflation terms and, contrary to empirical evidence, implies that inflation is not sticky. In fact, prior to the implementation of the forward-looking specifications, Phillips curves in policy models assumed that expectations were purely backward-looking. Although such specifications lacked the rational-expectations assumptions preferred when analyzing alternative policies, they captured the strong autocorrelations of actual inflation rates.

This paper discusses four potential sources of lag dynamics in inflation: non-rational behaviour, staggered contracting, frictions on price adjustment, and shifts in the long-run inflation anchor of agent expectations (the

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perceived inflation target). Many attempts to justify hybrid models with both backward- and forward-looking expectations assume non-rational behaviour of some sort. For example, Roberts (1997, 2001) and Ball (2000) assume that a fraction of agents use adaptive expectations; Gali and Gertler (1999) suggest that some firms use rule-of-thumb pricing; and Fuhrer and Moore (1995) use a real-wage-contracting specification where the price base of the real-wage comparison is not the average of prices expected over the life of the contract. Without relaxing the assumption of rational expectations, however, frictions on price adjustment can lead to a hybrid specification (Kozicki and Tinsley 2002).

The lag dynamics of inflation also may be influenced by shifts in the long-run anchor of agents' inflation expectations. Most policy models assume that the inflation target is known by all agents and that it doesn't change. However, learning about shifts in the policy target for inflation may be another source of persistence in the inflation process. Learning can significantly slow aggregate inflation adjustments, particularly after major changes in policy, as shown in Kozicki and Tinsley (2001a).

Section 1 reviews several models of inflation dynamics. The models include purely forward-looking specifications, as well as specifications that admit additional lags or leads of inflation. More complicated dynamic specifications are obtained with the introduction of non-rational agents, staggered contracting, or generalized frictions on price adjustment. Section 2 empirically examines the consistency of Canadian and U.S. inflation with the various sources of lag dynamics. Section 3 discusses monetary policy implications of the empirical results, and concluding comments are offered in the final section.

1 Sources of Lag Dynamics in Structural Models of Inflation

The benchmark for the discussion and analysis of the lag dynamics of inflation is the minimalist, purely forward-looking linear specification for inflation (π_t),

$$\pi_t = \beta E_t \pi_{t+1} + \gamma y_t + u_t, \quad (1)$$

as derived in closed-economy models of Yun (1996), Woodford (1996), or King and Wolman (1999).¹ In this expression, y_t is the output gap, u_t is a shock, and $E_t \pi_{t+1}$ denotes the expectation of π_{t+1} conditional on

1. Erceg, Henderson, and Levin (2000) develop a parallel description of the evolution of wages.

information available in t . McCallum and Nelson (1999, 2000) show how this specification can also apply in open-economy models if imports are treated as raw-material inputs to the home country's productive process. In fact, McCallum and Nelson (2000) and Kara and Nelson (2002) argue that this open-economy treatment implies more realistic inflation dynamics than standard alternatives.

Although it is the basis for many empirical studies, this forward-looking specification is a linearization around a constant long-run anchor for inflation expectations assumed to equal zero, or, in mathematical terminology, around a steady-state inflation rate of zero. However, the assumption that the long-run anchor for inflation expectations is zero, as made in most structural macroeconomic policy models, is empirically unreasonable. Long-run inflation expectations should converge to the perceived inflation target of monetary policy, or the inflation target if it is known and credible, and these targets tend to incorporate small positive inflation rates. Section 1.1 presents an expression for inflation similar to equation (1) that explicitly accounts for a non-zero steady-state inflation rate.

The main criticism offered against purely forward-looking expressions such as equation (1) is that they are inconsistent with empirical evidence of considerable persistence in inflation (Fuhrer 1997; Gali and Gertler 1999; and Roberts 1998). Section 1.2 follows the literature that assumes some form of non-rational behaviour to obtain more general expressions for inflation with additional sources of lag dynamics. Section 1.3 reviews specifications where lag dynamics result from staggered contracting. An alternative source of additional lag dynamics is rational behaviour in the presence of frictions on price adjustment. Such specifications are reviewed in section 1.4.²

2. Lag dynamics have been introduced using approaches other than those reviewed here. One alternative to introducing inflation stickiness is the recently proposed sticky-information model of price adjustment presented by Mankiw and Reis (2001) and empirically implemented for the United States, Canada, and the United Kingdom by Khan and Zhu (2002). Carroll (2001) derives an expression for inflation expectations identical to the one proposed by Mankiw and Reis, but based on microfoundations with the spread of information likened to the spread of a disease in models from theoretical epidemiology. Another alternative, proposed by Calvo, Celasun, and Kumhof (2000), applies to a world of positive (>0) steady-state inflation and assumes that when firms are allowed to reoptimize they choose both a reset price and the rule-of-thumb rate at which they will update prices until they next reoptimize. This approach gives rise to inflationary inertia.

1.1 Non-zero anchor for inflation expectations

This section presents an expression for inflation that allows for a non-zero anchor for inflation expectations. A non-zero anchor seems more realistic for empirical analysis. Since the end of 1995, the central tendency of the inflation target range of Canadian monetary policy has been 2 per cent. In the United States, through statements suggesting that the Federal Open Market Committee (FOMC) had achieved price stability even though measures of consumer inflation (and GDP price index inflation) were positive, at least some members of the FOMC have suggested that they personally believe the goal of policy is a small positive target based on measured inflation. For instance, in a speech in June 2002, President Broadus of the Federal Reserve Bank of Richmond commented: "... my own view is that a longer-term annual increase in the core personal consumption expenditures index of 1/2 per cent to 1 1/2 per cent is a good working definition of price stability in practice." On 10 June 2002, *The Inner City Reporter's Federal Reserve Beat* quoted Governor Kohn as saying, "I think it's very clear that the current rate of inflation is pretty darned low and we're getting awfully close to some zone of price stability, if we're not already in it." And, Robert Bartley reported in the *Opinion Journal* on 20 May 2002: "Fed officials point to the consumer price increase of only 1.4% in the last year, and similarly slow growth in more sophisticated indexes. New York Fed President William McDonough recently asked, 'If that's not price stability, what is?'"

In addition, evidence from long-horizon survey data suggests that the long-run anchor for inflation expectations has not been constant over the sample periods typically examined in empirical work (Figure 1). The constant-zero assumption on the inflation expectations anchor is likely to lead to particularly misleading empirical results if the steady-state inflation rate changed within a sample over which the specification is estimated. The phrases "steady-state inflation," "(long-run) anchor for inflation expectations," "nominal anchor," and "perceived inflation target" will be used interchangeably to refer to the value of inflation that is expected to obtain in the absence of shocks. Alternatively, since forecasts assume all future shocks will be zero, this will be the value to which long-run forecasts of inflation will converge. In a stable system, this will be what the market perceives the inflation target of monetary policy to be. The market perception of the inflation target is used so that the same model can be applied to countries with stable goals, whether or not their central banks have announced inflation targets. In addition, use of the market perception of the inflation target recognizes that market expectations will be anchored by what the market thinks the inflation target is. Kozicki and Tinsley

Figure 1
Long-horizon inflation expectations

Per cent



Sources: Survey of Professional Forecasters, Federal Reserve Bank of Philadelphia (United States); Consensus Forecasts (Canada).

(2001b) point out that in the presence of imperfect information, the perceived inflation target may differ from the true target of inflation, signalling a form of imperfect policy credibility.

An expression for inflation that allows for a non-zero inflation-expectations anchor is derived in the Appendix. As a starting point, this paper will use an approximation to that expression that closely resembles the benchmark in equation (1),

$$\hat{\pi}_t = bE_t\hat{\pi}_{t+1} + gy_t + \varepsilon_t. \quad (2)$$

In this expression, $\hat{\pi}_t$ represents the percentage deviation of inflation from the nominal anchor. Implications of non-rational behaviour will imply modifications to equation (2) just as they would for equation (1). An example is provided in section 1.2. Models with staggered contracts and frictions imply inflation expectations that are generalizations of equations (1) and (2). These specifications are introduced in sections 1.3 and 1.4.

The expression in equation (2) differs from the benchmark model in three ways. First, inflation appears as the deviation of inflation from the nominal anchor. Second, the functional relationship between the coefficients on expected inflation and the output gap and the structural parameters of the model are different. Third, embedded in the shock in equation (2) is a term

with a discounted sum of expected inflation deviations that is correlated with other regressors. As the nominal anchor approaches zero, all three of these differences shrink, and the expression in equation (2) converges to the benchmark model in equation (1).

The replacement of inflation with inflation deviations may lead to important differences in empirical studies of inflation dynamics, including descriptions of the degree of inflation persistence. If the nominal anchor is constant over the sample being examined, then, all else equal, estimates of inflation persistence and the properties of inflation dynamics are unlikely to be affected very much as long as estimated equations contain a constant term. However, if the nominal anchor has changed over the sample period, then empirical results may be considerably different. Stationary series with step changes are often mistaken for $I(1)$ processes, an empirical finding that exaggerates the degree of persistence in the series (Hendry and Neale 1991). The importance of accounting for shifts in steady-state inflation in an analysis of persistence in inflation is empirically examined in section 2.

The fact that the relationship between coefficients and structural parameters is different is less likely to be important for the empirical questions being addressed in this paper. Here, empirical results focus on estimates of coefficients such as b and g , rather than on the underlying structural parameters. While for given estimates of coefficients, estimates of structural parameters may be affected if the inflation expectations anchor is incorrectly assumed to be zero, effects are likely to be small if the anchor is close to zero. For Canada and the United States, the assumption that the nominal anchor is positive, but close to zero, is reasonable—especially for the era of inflation targeting in Canada and the Greenspan policy regime in the United States. Likewise, for a nominal anchor close to zero and plausible values of the structural parameters, the implied difference in coefficients between the benchmark and general specifications is likely to be small.

Compared with the expression derived in the Appendix, the approximation in equation (2) lumps a term that includes expected inflation deviations into ϵ_t . In addition to excluding a potentially important explanatory variable, the presence of this term in ϵ_t introduces a correlation between ϵ_t and the explanatory variables. However, as shown in the Appendix, for realistic parameterizations, the contribution of this term to movements in $\hat{\pi}_t$ is likely to be negligible, and the size of the bias will likely be very small. Consequently, the simpler approximation that more closely lines up with the standard approach was chosen to be the starting point for the analysis in this paper. More details on the size of the missing term and the relationships between b and β and between g and γ are provided in the Appendix.

1.2 Hybrid models resulting from non-rational behaviour

A standard criticism of purely forward-looking models of inflation such as equation (1) is that because the inflation rate doesn't depend on lagged inflation, it is completely flexible (Chadha, Masson, and Meredith 1992; Fuhrer and Moore 1992; and Fuhrer 1997). This seems at odds with empirical evidence for Canada and the United States, which finds considerable persistence in inflation.

One approach to introducing additional stickiness to inflation is to assume that a fraction of agents are backward-looking and use a simple autoregressive structure to forecast inflation (Roberts 1997, 2001). Suppose that a fraction ω of agents use a backward-looking proxy for expectations and assume inflation evolves according to

$$\hat{\pi}_t = b \sum_{i=1}^p A_i \hat{\pi}_{t-i} + g y_t + g \sum_{i=1}^p C_i y_{t-i} + \varepsilon_t, \quad (3)$$

while the remaining fraction, $1 - \omega$, of agents are purely forward-looking, as in equation (2). Aggregating across agents, a hybrid model of inflation with both forward-looking and backward-looking agents is obtained:

$$\hat{\pi}_t = b(1 - \omega) E_t \hat{\pi}_{t+1} + b\omega \sum_{i=1}^p A_i \hat{\pi}_{t-i} + g y_t + g\omega \sum_{i=1}^p C_i y_{t-i} + \varepsilon_t. \quad (4)$$

This expression resembles the typical hybrid specification, but with inflation replaced by deviations of inflation from the nominal anchor. For instance, if $A_i = 0$ for $i \neq 1$, with $0 < A_1 \leq 1$, and $C_i = 0$, then an expression similar to equation (3) in Roberts (2001) and to those estimated by Fuhrer (1997) is obtained. If $\omega = 1$, then the expression resembles a backward-looking Phillips curve such as implemented by Beaudry and Doyle (2001) and Fuhrer (2001) for Canada and Rudebusch and Svensson (1999) for the United States. Most empirical estimates of backward-looking Phillips curves assume $b \sum_{i=1}^p A_i = 1$ to preclude the existence of a permanent trade-off between inflation and unemployment.³

3. Most empirical implementations of backward-looking Phillips curves use the deviation of the unemployment rate from the non-accelerating-inflation rate of unemployment (the NAIRU) rather than the output gap. For more discussion of backward-looking Phillips curves, see Kozicki (2001) and the references therein.

1.3 Models with staggered contracts

Inflation stickiness can also be introduced using variants of the Taylor (1980) staggered-contracting framework. The typical model of inflation dynamics derived from a staggered-contracting specification does not rely on an assumption that the steady-state inflation rate be equal to zero. However, restrictions on the structure of the model imply that the model of inflation dynamics also applies to deviations of inflation from the nominal anchor.

Following the derivations outlined in Fuhrer and Moore (1995), the aggregate log price level, p_t , is a weighted average of the log contract prices, x_t , negotiated in the current and previous quarters that are still in effect. Letting h_i denote the proportions of outstanding contracts negotiated in $t-i$, and using the lag operator L where $L^i x_t \equiv x_{t-i}$, p_t satisfies

$$\begin{aligned} p_t &= \sum_{i=0}^{m-1} h_i x_{t-i} \\ &= h(L)x_t, \end{aligned} \quad (5)$$

assuming no contracts negotiated prior to $t-m+1$ are still in effect, i.e., the longest contract lasts m periods. The distribution of outstanding contracts must satisfy $h(1) = 1$. In the standard contracting specification, the current nominal-wage contract, x_t , depends on the price level expected to prevail over the life of the contract, adjusted for excess demand conditions,

$$\begin{aligned} x_t &= \sum_{i=0}^{m-1} h_i E_t(p_{t+i} + \gamma y_{t+i}) \\ &= E_t h(L^{-1})(p_t + \gamma y_t). \end{aligned} \quad (6)$$

Combining equation (5) with equation (6) and using $h(1) = 1$ results in the price expression

$$p_t = h(L)E_t h(L^{-1})(p_t + \gamma y_t). \quad (7)$$

For two-period staggered contracts with half of all contracts negotiated each period, Fuhrer and Moore (1995) show that equation (7) simplifies to a purely forward-looking expression similar to equation (1) with $\beta = 1$. In other words, for $m = 2$, although wages and prices are sticky, inflation is not. For $m > 2$, staggered Taylor-style contracting implies that inflation depends on additional lags and leads of inflation,

$$\pi_t = E_t \pi_{t+1} + \sum_{i=2}^{m-1} \left(\sum_{j=i}^{m-1} G_j \right) (E_t \pi_{t+i} - \pi_{t-i+1}) \\ + \gamma \sum_{i=1}^{m-1} G_i (E_t y_{t+i} + y_{t-i}) + \gamma G_0 y_t + \text{resid}_{T,t}, \quad (8)$$

where the coefficients G_j are non-linear functions of the contract proportions h_i , and $G_1 = 1 - \sum_{i=2}^{m-1} G_i$.⁴

The derivation of equation (8) did not require an assumption that the steady-state inflation rate is zero. However, because the sum of coefficients on lags and leads of inflation on the right side of equation (8) is equal to unity, the expression also holds in deviation from steady-state form:

$$\hat{\pi}_t = E_t \hat{\pi}_{t+1} + \sum_{i=2}^{m-1} \left(\sum_{j=i}^{m-1} G_j \right) (E_t \hat{\pi}_{t+i} - \hat{\pi}_{t-i+1}) \\ + \gamma \sum_{i=1}^{m-1} G_i (E_t y_{t+i} + y_{t-i}) + \gamma G_0 y_t + \text{resid}_{T,t}. \quad (9)$$

To induce additional inflation stickiness, Fuhrer and Moore (1995) and Fuhrer (1997) explored the consequences of a relative-contracting specification developed by Buiter and Jewitt (1981). The Fuhrer-Moore specification assumes that agents set nominal contract prices so that the current real contract index depends on the real contract index expected to prevail over the life of the contract, adjusted for excess demand conditions, with the real contract index defined as a combination of real contract wages negotiated on the contracts currently in effect. With relative contracting, an expression for inflation that resembles the expression for prices in equation (7) is obtained:

$$\pi_t = h(L) E_t h(L^{-1}) (\pi_t + \gamma g^{-1}(L) y_t), \quad (10)$$

where $g(L) = \sum_{i=1}^{m-1} g_i L^{i-1}$ with $g_i = \sum_{j=i}^{m-1} h_j$. Fuhrer-Moore contracting implies that for $m > 2$, inflation evolves according to:

4. This expression replaces lagged conditional expectations of lagged variables, $E_{t-k} y_{t-l}$, for $k > l$, with y_{t-l} . The difference between the conditional expectation and the observation is included in the error term and implies that the error term may be serially correlated. Guerrieri (2002) provides a careful derivation for the case of $m = 2$ that doesn't make this substitution.

$$\pi_t = \pi_{t-1} + (E_t \pi_{t+1} - \pi_t) + \sum_{i=2}^{m-1} \left(\sum_{j=i}^{m-1} G_j \right) (E_t \pi_{t+i} - E_t \pi_{t+i-1}) \\ - \sum_{i=2}^{m-1} \left(\sum_{j=i}^{m-1} G_j \right) (\pi_{t-i+1} - \pi_{t-i}) + \gamma h(L) E_t h(L^{-1}) g^{-1}(L) y_t + \text{resid}_{F,t}, \quad (11)$$

or, after rearrangement,

$$\pi_t = (1/2) \sum_{i=1}^{m-1} G_i (E_t \pi_{t+i} + \pi_{t-i}) \\ + (1/2) \gamma h(L) E_t h(L^{-1}) g^{-1}(L) y_t + \text{resid}_{F,t}. \quad (12)$$

In these expressions, the coefficients, G_i , are the same non-linear functions of the contract proportions, h_i , as in the Taylor specification, and as before, $G_1 = 1 - \sum_{i=2}^{m-1} G_i$. Once again, because the coefficients on the lags and leads of inflation on the right side of equation (12) sum to one, the expression also holds in deviation from steady-state form:

$$\hat{\pi}_t = (1/2) \sum_{i=1}^{m-1} G_i (E_t \hat{\pi}_{t+i} + \hat{\pi}_{t-i}) \\ + (1/2) \gamma h(L) E_t h(L^{-1}) g^{-1}(L) y_t + \text{resid}_{F,t}. \quad (13)$$

The Fuhrer-Moore specifications imply different coefficients on inflation leads and lags than the Taylor specifications. The most noticeable difference is that in the Fuhrer-Moore specifications, coefficients on all leads and lags are positive, while in the Taylor specifications, coefficients on leads are positive but those on lags are negative. A second difference is that, since the G_i s are positive, coefficients in the Taylor specifications decrease in magnitude as the lag/lead order increases, while those in the Fuhrer-Moore specifications are not similarly constrained.

One important difference between inflation specifications that assume a fraction of the population form expectations non-rationally versus those that assume staggered contracts, is the appearance of additional leads of inflation as explanatory variables. For contract lengths greater than two, the Taylor and Fuhrer-Moore specifications imply that inflation will depend on additional leads of expected inflation as well as additional lags. By contrast, as the lag length of the time-series forecasting model used by non-rational agents increases, only extra lags appear in the model with non-rational forecasting agents, equation (4).

A second difference in the specifications is that the Taylor and Fuhrer-Moore inflation expressions include lags and leads of the output gap rather than just the contemporaneous output gap. Although the hybrid model presented in section 1.2 did not include lags of the output gap, if non-rational agents were to use lags of both output and inflation to forecast output, then lags of the output gap would also appear in the hybrid specification. However, the presence of non-rational agents that use a reduced-form time-series model to forecast would not result in the appearance of leads of the output gap in hybrid specifications.

1.4 Generalized frictions on price adjustment

Section 1.2 described how additional sources of lag dynamics can be introduced into models of inflation by relaxing the assumption of rational expectations. Section 1.3 reviewed how staggered-contracting specifications can also result in more complicated lag dynamics. An alternative proposed by Kozicki and Tinsley (1999a), with explicit derivations for inflation in Kozicki and Tinsley (2002), assumes that expectations are formed rationally, but that there are frictions on price adjustment.

This section's approach may be better viewed as a general approach rather than one with a different motivation from some of the models already discussed. In particular, in the Taylor staggered-contracts model and in the Calvo (1983) assumptions behind the purely forward-looking specifications in equations (1) and (2), it is also true that expectations are formed rationally, and price stickiness derives as a result of assumptions that there are frictions associated with price adjustment. Furthermore, as will be discussed, New Keynesian Phillips curves implied by the Calvo, Taylor, and Fuhrer-Moore formulations can be derived as special cases of the generalized-frictions approach (although the coefficients may have different structural interpretations in the various formulations).

Frictions on price adjustment may include factors that lead to lags between cost changes and price adjustment, the deterrent effect of concerns that competitors will not also adopt price increases, and the reluctance of firms to antagonize customers. These three factors were identified as important potential explanations of price stickiness in a report by Blinder et al. (1998) on the results of a survey of heads of small companies and appropriate officers of large corporations. Alternatively, frictions may be due to managerial and customer costs associated with price adjustment, as examined by Zbaracki et al. (2003). They provide explicit estimates of costs of price adjustment and determine that managerial and customer costs are substantial (more than an order of magnitude larger than menu costs) and,

importantly, that these costs appear to be convex functions of the size of the price change.

The frictions approach (or polynomial adjustment-cost approach) does not require an assumption that the nominal anchor be equal to zero. The review below provides examples of conditions and modifications that result in models of the dynamics of inflation and in models of the deviation of inflation from the nominal anchor.

In Kozicki and Tinsley (2002), optimal intertemporal planning is captured by assuming that agents choose their relative price to minimize percentage deviations from the optimal relative price path subject to frictions on price adjustment. The planning problem can be stated as:

$$\min_p E_t \left\{ \sum_{i=0}^{\infty} \beta^i \left[(1/2)(p_{t+i} - p_{t+i}^*)^2 + (1/2)(v(L)p_{t+i})^2 \right] \right\}, \quad (14)$$

where $v(L) = v_0 + v_1L + \dots + v_{m-1}L^{m-1}$ is an $(m-1)$ order frictions polynomial in the lag operator, L , and $v(1) = 0$ to capture that frictions are binding only in disequilibrium. Use of a quadratic loss function to model frictions or adjustment costs associated with price changes may be justified by, for example, the convex managerial and customer costs identified by Zbaracki et al. (2003) and their claim that customer-antagonism costs can arise through any price change—either a decrease or an increase. The implied expression for inflation under agent optimization is:

$$\pi_t = \sum_{i=1}^{m-1} \left(\sum_{j=i}^{m-1} \beta^j G_j \right) E_t \pi_{t+i} - \sum_{i=2}^{m-1} \left(\sum_{j=i}^{m-1} G_j \right) \pi_{t-i+1} + \gamma^* y_t + \text{resid } p_{t,i}, \quad (15)$$

where $p_t^* - p_t = \gamma^* y_t$ has been assumed as in Kozicki and Tinsley (2002) and the coefficients are functions of the coefficients in the frictions polynomial, $G_i = f_i / (\sum_{j=1}^{m-1} f_j)$ with $f_i \equiv -\sum_{j=0}^{m-i-1} v_j v_{j+i} \beta^j$.

As in the staggered-contracting specifications, the frictions approach results in an expression with additional leads as well as lags of inflation. This expression closely resembles that obtained under Taylor contracting in equation (8). In particular, if $\beta = 1$, then equations (15) and (8) differ only in the way the output gap enters the expression, with the frictions-based expression corresponding to a Taylor-contracting specification derived using a slightly modified version of equation (7):

$$p_t = E_t h(L) h(L^{-1}) p_t + \gamma y_t. \quad (16)$$

For the special case when $m = 2$, the planning problem in equation (14) corresponds to the quadratic adjustment-cost model of Rotemberg (1982), and, as noted by McCallum and Nelson (1999), implies the purely forward-looking expression for inflation in equation (1). If $\beta = 1$, then equation (15) also holds with inflation replaced by the percentage deviation of inflation from the nominal anchor:

$$\hat{\pi}_t = E_t \hat{\pi}_{t+1} + \sum_{i=2}^{m-1} \left(\sum_{j=i}^{m-1} G_j \right) (E_t \hat{\pi}_{t+i} - E_t \hat{\pi}_{t-i+1}) + \gamma^* y_t + \text{resid}_{p,t}. \quad (17)$$

This expression closely resembles equation (9), although only the contemporaneous output gap appears here. However, if $\beta \neq 1$, then this expression will only hold approximately.

The adjustment-cost formulation can also support a structure similar to that obtained by Fuhrer and Moore. In particular, to maintain the assumption that frictions are binding only in disequilibrium when the nominal anchor is non-zero, it may be more appropriate to assume that the frictions polynomial applies to inflation deviations, i.e., that frictions are binding only when inflation deviates from the nominal anchor. In this case, the planning problem can be restated as

$$\min_p E_t \left\{ \sum_{i=0}^{\infty} \beta^i \left[(1/2)(p_{t+i} - p_{t+i}^*)^2 + (1/2)(v(L)\hat{\pi}_{t+i})^2 \right] \right\}. \quad (18)$$

This formulation may be motivated, for instance, by a view that consumers may be antagonized by price changes that they do not regard as "fair," as in Rotemberg (2002). He suggests that "If recent inflation has been relatively low, [customers] are likely to believe that cost increases have been modest and [they] are likely to be less tolerant of price increases." Zbaracki et al. (2003) cite a pricing manager in the 1970s as observing: "The [cost] increases we experienced during that [inflationary] time were very much largely driven by cost and our average costs were going up and we were trying to recoup that. . . . [During the] high-inflation period you could get away with the high price increases. I think there [were] expectations in the market place; our customers [were] saying 'I am able to inflate my prices to the end user so I shouldn't be surprised when my vendor raises their prices. . . .'" If the perceived inflation target is used by consumers to estimate cost increases and gauge whether price changes are reasonable,

then frictions would apply to deviations of inflation from the perceived inflation target.

Optimization of equation (18) implies an expression for the change in inflation that is similar to equation (15). After manipulation, inflation can be shown to evolve according to:

$$\dot{\pi}_t = \sum_{i=1}^{m-1} G_i(\beta^i E_t \dot{\pi}_{t+i} + \dot{\pi}_{t-i}) \left(1 + \sum_{j=1}^{m-1} G_j \beta^j \right) + \gamma^{**} y_t + \text{resid}_{D,t}. \quad (19)$$

For $\beta = 1$, the frictions-based expression corresponds to a Fuhrer-Moore contracting specification based on this modified version of equation (10),

$$\pi_t = E_t h(L) h(L^{-1}) \pi_t + \gamma y_t, \quad (20)$$

and equation (19) simplifies to equation (13) but with leads and lags of the output gap replaced by the contemporaneous output gap.

The next section will examine whether empirical evidence favours specifications with non-rational expectations formations as in equation (4), Taylor-type staggered contracting as in equation (8) or (9), Fuhrer and Moore staggered contracting as in equation (12) or (13), or rational adjustment in the presence of generalized frictions as in equations (15), (17), or (19).

2 An Empirical Analysis of the Sources of Inflation Persistence

This section examines the persistence properties of Canadian and U.S. inflation and assesses which of the various models of lag dynamics seem to be most consistent with the data. The first subsection estimates time series for the nominal anchor in Canada and the United States. The second subsection summarizes the persistence properties of inflation and examines to what extent shifts in the nominal anchor may explain observed persistence. The third subsection contrasts results from estimates of structural models of inflation dynamics, including purely forward-looking expressions, hybrid models that assume partially non-rational expectations formation, expressions based on staggered-wage contracting, and models with rational expectations and generalized frictions on price adjustment.

2.1 Historical estimates of the perceived inflation target

Kozicki and Tinsley (2001c) argue that there have been shifts in the perceived long-run inflation target of monetary policy in the United States.

Such shifts explain low-frequency movements in long-horizon inflation expectations evident in survey data (Figure 1) and help resolve empirical puzzles in the U.S. Treasury term structure (Kozicki and Tinsley 2001a, 2001b, 2001c).⁵ Estimates of a perceived inflation-target series based on breakpoint tests are provided in Kozicki and Tinsley (2001a, 2001c). Cogley and Sargent (2001) estimate long-horizon forecasts of inflation that shift considerably over 1965–2000.

Empirical evidence suggests that there have been shifts in the conditional mean of the inflation process in Canada as well. Laxton, Ricketts, and Rose (1994) estimate a three-state model of Canadian inflation; and Perron (1994) provides evidence suggesting that the mean of Canadian inflation has shifted. Hostland (1995) documents that the time-series properties of Canadian inflation were quite different from the mid-1950s to the early 1970s than before and after this period. And, although only available for a relatively short sample, the long-horizon survey data shown in Figure 1 support the view that there have been shifts in the nominal anchor in Canada.

While using directly observable information on shifts in the anchor to long-horizon inflation expectations would be preferable, insufficient data are available. Long-horizon survey data might provide one proxy for the nominal anchor, but such data are available only since 1979 for the United States and since 1990 for Canada. Another alternative for Canada is to use the midpoint of the inflation-control target range. However, such a range is available only since 1991 and if the policy wasn't regarded as credible, the anchor for long-run inflation expectations could possibly have differed from the midpoint of the range. Consequently, the approach taken in this paper is to estimate a series to proxy for the nominal anchor. Survey data are then used as a check on whether or not the estimated series for the nominal anchor is reasonable.

A reduced-form procedure similar to that described in Kozicki and Tinsley (1999b) is used to estimate the anchor of long-horizon inflation expectations. For each country, a four-variable vector autoregression (VAR) with shifting endpoints is used to proxy for agent expectations.⁶ The variables included in the VAR are quarterly data on the output gap, y_t , inflation, π_t , a 10-year nominal government yield, $R_{10,t}$, and a short-term real interest rate, r_t (constructed as the difference between an observed nominal short-term

5. Missing observations for long-horizon survey data are linearly interpolated from observations for surrounding quarters.

6. The use of shifting, or moving, endpoints in AR and VAR time-series models is discussed in Kozicki and Tinsley (1998, 2001a, 2001b, 2001c).

interest rate and inflation over the previous quarter).⁷ Each variable appears in the VAR in deviation from steady-state form, and each deviation variable is assumed to be stationary. Thus, any source of non-stationarity derives from shifts in the steady state. Four steady-state variables are included in the model: the equilibrium real short-term interest rate, μ , the 10-year term premium, ϕ , the steady-state output gap, $\bar{y}$, and the long-run anchor of inflation expectations, $\bar{\pi}^p$ (i.e., the perceived inflation target). The equilibrium real rate, the term premium, and the steady-state output gap are assumed to be constant, while the data are allowed to determine whether and how the inflation steady state varies.⁸

The reduced-form model assumes that the dynamics of the deviations of the variables from their steady states are well described by a four-lag VAR. In each quarter, updates to agents' perceptions about the perceived inflation target are assumed to be independent normal innovations. The reduced-form model is:

$$\begin{bmatrix} y_t \\ \pi_t \\ R_{10,t} \\ r_t \end{bmatrix} = A(L) \begin{bmatrix} y_t \\ \pi_t \\ R_{10,t} \\ r_t \end{bmatrix} + (I - A(1)) \begin{bmatrix} \bar{y} \\ \bar{\pi}_t^p \\ \mu + \bar{\pi}_t^p + \phi \\ \mu \end{bmatrix} + u_t, \quad (21)$$

where $A(L) = A_1 L + A_2 L^2 + A_3 L^3 + A_4 L^4$ and updates to the perceived inflation target follow

$$\bar{\pi}_{t+1}^p = \bar{\pi}_t^p + v_t. \quad (22)$$

The innovations u_t and v_t are assumed to be uncorrelated across time and with each other. The model was estimated using maximum likelihood with Kalman filtering techniques to deal with the unobserved state variable, $\bar{\pi}_t^p$.

7. For the United States, Congressional Budget Office estimates are used for the output gap, the federal funds rate is used as a short-term interest rate, and inflation is measured using the GDP price index. For Canada, the output gap is estimated using a Hodrick-Prescott filter with smoothing parameter equal to 1,600, a three-month government bill rate is used as a short-term interest rate, and inflation is measured using the CPI. The price index choices were made to match series for which near-term quarterly survey forecasts are available.

8. The steady-state output gap is allowed to be non-zero for empirical reasons. The theoretical steady-state output gap is zero. However, the average output gap may be non-zero over some samples, and the econometric procedure maps the sample average into the steady-state estimate.

Figure 2
U.S. inflation and the estimated nominal anchor



Sources: Bureau of Economic Analysis, U.S. Department of Commerce; Survey of Professional Forecasters, Federal Reserve Bank of Philadelphia; authors' calculations.

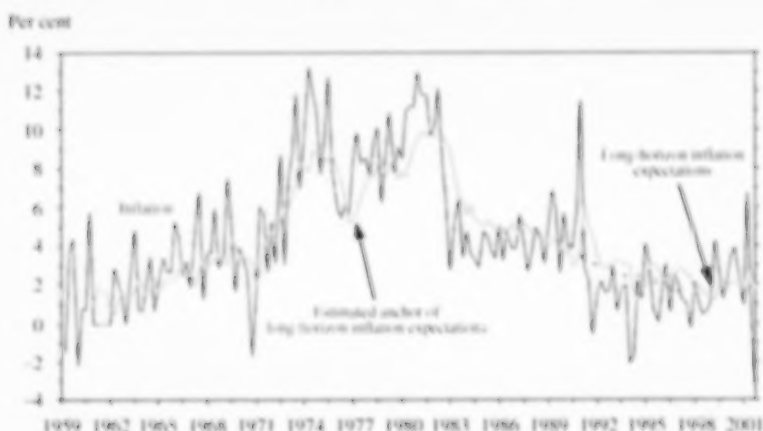
The variance of innovations to the state variable was chosen to match the variance of innovations to available long-horizon survey data.

Figure 2 shows inflation, the estimated anchor of long-horizon inflation expectations, and survey data on 10-year inflation expectations for the United States.⁹ The estimated nominal anchor is the unsmoothed estimate of the state variable from the Kalman filter ($E_{t-1}\pi_t^p$). The estimated nominal anchor follows the trajectory of the survey data quite well. After a period of elevated inflation in the mid- to late-1970s, the nominal anchor was quite high. However, the nominal anchor gradually declined through the 1980s as the lower inflation rate obtained under Volker was not reversed. An interesting feature of both the survey data and the estimated nominal anchor is that the series remained above the actual inflation rate for most of the 1980s and 1990s. One possible explanation of this gap is that the FOMC did not have full credibility in its efforts to achieve price stability.

Figure 3 shows results for Canada. The estimated nominal anchor for Canada is closer to actual Canadian inflation than was the case for U.S. data. Since 1994, the estimated nominal anchor and the survey data are close to the central tendency of Canadian inflation and to the central tendency (2 per

9. The survey series is missing observations for some quarters. Missing observations were linearly interpolated.

Figure 3
Canadian inflation and the estimated nominal anchor



Sources: Bank of Canada; Consensus Forecasts; authors' calculations.

cent) of the inflation-control target range (not shown in Figure 3). In fact, the survey data lie inside the inflation-control target range from the inception of the new policy regime. These results suggest that the Bank of Canada's inflation-control targeting regime has been credible.

2.2 Reduced-form estimates of inflation persistence

This section investigates to what extent persistence in inflation may be linked to shifts in the nominal anchor for inflation expectations rather than to sluggishness of inflation dynamics in the presence of a constant steady state. Inflation persistence is measured as the sum of coefficients from an estimated AR(4) model of inflation. Time-series models are estimated over 1962–2001 and various subsamples. Models are estimated using raw inflation data, deviations of inflation from the estimated nominal anchor, deviations of inflation from long-horizon survey data (over those subsamples for which survey data are available), and deviations of inflation from a spliced nominal-anchor series that uses Kalman estimates only when survey data are unavailable. If some of the sluggishness of inflation is associated with shifts in the nominal anchor, then estimates of persistence should be smaller for inflation deviations and over subsamples where shifts in the nominal anchor were less likely to have occurred (the 1990s).

Table 1
Estimates of inflation persistence

Estimation sample	Inflation	Inflation deviations	Survey deviations	Spliced deviations
United States				
1962Q1–2001Q4	0.94 (0.04)	0.80 (0.07)		0.81 (0.07)
1962Q1–1970Q4	0.92 (0.10)	0.54 (0.24)		0.54 (0.24)
1971Q1–1984Q4	0.85 (0.10)	0.75 (0.12)		0.76 (0.13)
1985Q1–2001Q4	0.83 (0.12)	0.74 (0.13)	0.53 (0.18)	0.53 (0.18)
1992Q1–2001Q4	0.39 (0.26)	0.78 (0.18)	0.53 (0.28)	0.53 (0.28)
Canada				
1962Q1–2001Q4	0.90 (0.05)	0.46 (0.13)		0.47 (0.13)
1962Q1–1970Q4	0.54 (0.22)	0.03 (0.41)		0.03 (0.41)
1971Q1–1984Q4	0.77 (0.11)	0.56 (0.20)		0.56 (0.20)
1985Q1–2001Q4	0.68 (0.16)	0.16 (0.22)		0.23 (0.22)
1992Q1–2001Q4	-0.01 (0.33)	0.14 (0.27)	0.21 (0.29)	0.21 (0.29)

Note: Entries are sum of coefficients in an AR(4) model of inflation with standard errors provided in parentheses.

Results are presented in Table 1. For U.S. data, inflation persistence is much lower in the 1990s than for any other subsample examined or for the full sample. These results are consistent with evidence reported by Cogley and Sargent (2001) and Willis (2003). Survey data on inflation expectations and movements in actual inflation were, on average, much flatter over this period than over any other. Thus, this result supports the view that some of the persistence in U.S. inflation may be due to shifts in the nominal anchor. Also supporting this view, for all other subperiods, persistence of inflation exceeds persistence of deviations of inflation from the estimated nominal anchor, from the survey data, and from the spliced series. This result is consistent with Levin and Piger (2002), who find that conditional on a statistically detected break in the intercept and innovation variance, inflation exhibits less persistence.

Results for Canada are stronger than those for the United States. Estimates of inflation persistence are lower in every subsample than over the full 1962–2001 sample. In fact, inflation persistence disappears entirely during the inflation-targeting regime. Results based on inflation deviations offer

further support that in Canada, most of the persistence in inflation is due to shifts in the nominal anchor. Very little persistence remains after such shifts have been removed.

2.3 Estimates of forward-looking models of inflation

The empirical results from the previous section suggest that shifts in the long-run anchor of inflation expectations help explain the observed persistence of inflation. Inflation persistence was estimated to be considerably lower since 1992, a period with relatively small movements in long-run inflation expectations, than in earlier periods. In addition, after accounting for shifts in the anchor for long-run inflation expectations, inflation persistence declines for both countries (although considerably more for Canada). However, these results were based on estimation of reduced-form autoregressive models of inflation. This section provides more structure to the analysis, and takes the models described in the previous section to the data.

All of the models outlined in section 1 include conditional expectations of future inflation (and perhaps future output gaps) as explanatory variables. Following Roberts (1997), survey data are used to proxy for the conditional expectations of inflation.¹⁰ U.S. survey data are taken from the Survey of Professional Forecasters, published by the Federal Reserve Bank of Philadelphia. Forecasts of U.S. inflation are constructed from forecasts of the implicit GDP price deflator starting in 1992, and from forecasts of the GNP price deflator prior to 1992. Quarterly forecasts of one-quarter through four-quarter-ahead inflation are available starting from the fourth quarter of 1969. Canadian survey data are taken from Consensus Forecasts. Quarterly forecasts of one-quarter through four-quarter-ahead inflation are available from the second quarter of 1990. A few missing observations were encountered early in the sample. Missing observations for $E_t \pi_{t+k}$ were interpolated as the average of $E_{t-1} \pi_{t+k+1}$ and $E_{t+1} \pi_{t+k-1}$. In estimations that use inflation deviations instead of inflation, the nominal anchor is approximated using the spliced series that approximates the nominal anchor with long-horizon survey expectations when available, and using the Kalman-estimated nominal anchor prior to the availability of the survey data.

Some of the models include expectations of future values of the output gap. For both countries, ex post values of the output gap are used for future values. To account for potential correlation between contemporaneous (and

10. Roberts (1997) provides a discussion of the properties of surveys of inflation expectations.

future) values of the output gap and equation errors, estimation proceeds using instrumental variables with the relevant survey data for that estimation, four lags of the output gap, and four lags of inflation used as instruments.

Unfortunately, the sample over which the models can be estimated is constrained because of limited survey data. For the United States, estimation is based on data from the fourth quarter of 1969 through the fourth quarter of 2001 and, for Canada, estimation is over data from the second quarter of 1990 through the fourth quarter of 2001.¹¹

Estimates of the benchmark model (equation 1) and the approximating model (equation 2) for the non-zero steady-state inflation case are provided in Table 2. Results are presented for estimated β and for β constrained to equal one. The purely forward-looking model of inflation does not fit U.S. data well. Q -statistics strongly reject the null hypothesis of no serial correlation up to lags 4 and 8. This is true for both inflation and inflation deviations. The inability of the model to explain inflation should not be surprising given the evidence, presented in Table 1, of considerable persistence in both inflation and inflation deviations (in all cases but the 1990s for inflation).¹²

Results for Canada are less pessimistic for the purely forward-looking model. Although there is weak evidence of residual serial correlation in the estimates for inflation with β restricted to equal one, the model tends to fare better when β and b are estimated, and when the model is applied to inflation deviations. Estimates of β and b seem somewhat small, however. One possible reason for this is that estimates are biased owing to omitted variables. Although Q -statistics do not detect significant serial correlation in residuals, these tests may have low power given the limited sample. The possibility that low estimates of β and b are due to omitted variables will be explored as additional sources of lag dynamics are added to the structure.

Empirical results from estimation of hybrid models that assume that a fraction of agents form expectations non-rationally are provided in Table 3.

11. Robustness of results for the United States was examined by also estimating the models over 1990Q2 to 2001Q4 for U.S. data. Differences between the qualitative results for the sample examined in the paper and those for the shorter sample are discussed in footnotes. One empirical complication not addressed in the paper is whether the results are sensitive to the use of 2002 vintage price data in combination with real-time survey data. However, as differences between real-time and latest available data are likely to be smaller for more recent samples, results from analysis of the shorter sample are less likely to be driven by data vintage mismatches.

12. When estimated over 1990Q2 through 2001Q4, the U.S. data no longer rejected the null hypothesis of no residual serial correlation.

Table 2
Estimates of purely forward-looking models of inflation

$infl_t = c_1 + (b \text{ or } \beta)E_t infl_{t+1} + \gamma y_t + resid_t$						
Inflation variable	γ	β	b	Q(4)	Q(8)	S.E.
United States						
$infl_t \equiv \pi_t$	0.144 (0.047)	1.00		0.000	0.000	1.15
$infl_t \equiv \pi_t$	0.198 (0.047)	1.180 (0.050)		0.000	0.000	1.11
$infl_t \equiv \hat{\pi}_t$	0.146 (0.046)		1.00	0.000	0.000	1.15
$infl_t \equiv \hat{\pi}_t$	0.159 (0.045)		1.419 (0.124)	0.000	0.000	1.11
Canada						
$infl_t \equiv \pi_t$	0.631 (0.228)	1.00		0.076	0.275	2.26
$infl_t \equiv \pi_t$	0.613 (0.214)	0.402 (0.223)		0.259	0.570	2.12
$infl_t \equiv \hat{\pi}_t$	0.621 (0.228)		1.00	0.075	0.272	2.26
$infl_t \equiv \hat{\pi}_t$	0.602 (0.204)		0.025 (0.280)	0.451	0.816	2.02

Notes: Standard errors of coefficient estimates are provided in parentheses. Entries in columns Q(4) and Q(8) are p -values for Q -statistics for the null hypothesis of no serial correlation up to lags 4 and 8, respectively. The column labelled S.E. contains the regression standard error.

Results are presented for both inflation and inflation deviations, even though the model for inflation is misspecified in the presence of a non-zero nominal anchor. During estimation, non-rational agents were assumed to use only lags of inflation and the contemporaneous output gap to forecast inflation, i.e., $C_i = 0$ for $i = 1, \dots, p$ in equation (3). No constraints on the sum of coefficients on expected inflation and lags of inflation were imposed during estimation. For U.S. data, estimates of ω and ωA_i imply that the non-rational agents use a model with considerable inflation persistence. The sums of coefficients on lags of inflation in the implied forecasting model used by rational agents equal $\sum_{i=1}^m \omega A_i / \omega$ and exceed one for all values of m and both inflation and inflation deviations.¹³ For Canadian data, empirical results suggest that non-rational agents use a model with less

13. For the shorter sample, $\sum_{i=1}^m \omega A_i / \omega$ is close to one for inflation, but somewhat smaller than one for inflation deviations. Obtaining a smaller sum for inflation deviations is consistent with the earlier result that inflation persistence declines after controlling for shifts in the nominal anchor.

Table 3
Estimates of hybrid models of inflation persistence

$\text{infl}_t = c_1 + g y_t + (1 - \omega) E_t \text{infl}_{t+1} + \omega(A_1 \text{infl}_{t-1} + A_2 \text{infl}_{t-2} + A_3 \text{infl}_{t-3} + A_4 \text{infl}_{t-4}) + \text{resid}_t$									
Lags	g	ω	ωA_1	ωA_2	ωA_3	ωA_4	Q(4)	Q(8)	S.E.
United States—Inflation ($\text{infl}_t \equiv \pi_t$)									
1	0.155 (0.042)	0.358 (0.102)	0.470 (0.080)				0.033	0.156	0.98
2	0.160 (0.043)	0.375 (0.108)	0.444 (0.096)	0.043 (0.087)			0.030	0.152	0.99
3	0.184 (0.044)	0.428 (0.109)	0.438 (0.095)	-0.066 (0.100)	0.178 (0.085)		0.106	0.284	0.97
4	0.208 (0.045)	0.436 (0.109)	0.403 (0.097)	-0.060 (0.100)	0.097 (0.099)	0.130 (0.085)	0.774	0.858	0.97
United States—Inflation deviations ($\text{infl}_t \equiv \hat{\pi}_t$)									
1	0.128 (0.040)	0.123 (0.143)	0.421 (0.072)				0.005	0.017	0.99
2	0.133 (0.041)	0.145 (0.146)	0.378 (0.088)	0.068 (0.080)			0.005	0.019	0.99
3	0.153 (0.041)	0.163 (0.144)	0.356 (0.087)	-0.039 (0.092)	0.183 (0.079)		0.007	0.026	0.97
4	0.181 (0.041)	0.123 (0.141)	0.294 (0.088)	-0.042 (0.090)	0.063 (0.089)	0.217 (0.079)	0.737	0.926	0.95
Canada—Inflation ($\text{infl}_t \equiv \pi_t$)									
1	0.542 (0.221)	0.748 (0.256)	0.194 (0.165)				0.654	0.893	2.11
2	0.558 (0.222)	0.569 (0.310)	0.195 (0.165)	-0.183 (0.179)			0.651	0.849	2.11
3	0.608 (0.231)	0.299 (0.458)	0.156 (0.173)	-0.212 (0.184)	-0.185 (0.229)		0.710	0.853	2.12
4	0.655 (0.245)	-0.156 (0.858)	0.091 (0.203)	-0.299 (0.231)	-0.269 (0.267)	-0.184 (0.292)	0.833	0.901	2.13
Canada—Inflation deviations ($\text{infl}_t \equiv \hat{\pi}_t$)									
1	0.542 (0.214)	1.078 (0.302)	0.151 (0.162)				0.712	0.947	2.02
2	0.564 (0.216)	0.904 (0.356)	0.145 (0.163)	-0.162 (0.175)			0.812	0.955	2.03
3	0.606 (0.229)	0.699 (0.499)	0.116 (0.172)	-0.188 (0.182)	-0.132 (0.224)		0.883	0.964	2.05
4	0.618 (0.243)	0.608 (0.760)	0.102 (0.193)	-0.207 (0.217)	-0.149 (0.250)	-0.039 (0.243)	0.910	0.970	2.07

Notes: Standard errors of coefficient estimates are provided in parentheses. Entries in columns Q(4) and Q(8) are p -values for Q -statistics for the null hypothesis of no serial correlation up to lags 4 and 8, respectively. The column labelled S.E. contains the regression standard error.

persistence than was the case for U.S. data. The sums of coefficients on lags of inflation in the implied forecasting model are generally considerably less than one.

For the two countries and for both inflation and inflation deviations, the hybrid models generate considerable improvement in fit compared with the purely forward-looking models with plausible values of β or b . The hybrid model that obtains the lowest standard error of U.S. inflation residuals models the evolution of inflation deviations using four lags of inflation deviations.¹⁴ Consistent with the interpretation that shifts in the nominal anchor help explain U.S. inflation persistence, estimates of ω are lower when the model is estimated using inflation deviations rather than raw inflation. Interpretation of results is difficult, however. The null hypothesis that no agents are non-rational ($H_0: \omega = 0$) cannot be rejected; but, if this is the case, then contrary to the empirical results, no additional lags of inflation deviations should be significant!¹⁵ Perplexing results are also obtained for Canadian data. Both of the one-lag models find that a statistically significant fraction of agents are backward-looking (as does the two-lag model for inflation deviations), but point estimates of the coefficients on lagged inflation are small in magnitude and insignificantly different from zero.

These results highlight some of the difficulties associated with interpreting results from estimated hybrid models. In addition to the contradictory results discussed above, with the introduction of non-rational agents, the form of the forecasting model assumed to be used by these agents alters the interpretation of the structure. For instance, a large collection of reduced-form forecasting models could be used to represent the expectations formation of the non-rational agents. The hybrid expression for inflation provided in section 1.2 allowed for the possibility that non-rational agents used lags of inflation and the output gap to forecast inflation. However, VAR forecasting systems with more variables could also have been used. Alternatively, if non-rational agents use only lags of inflation to forecast

14. A model with three (or more) lags of inflation, $m = 3$, appears to fit the U.S. raw inflation data quite well, with no evidence of residual serial correlation. For this specification, the empirical results suggest that about 43 per cent of agents form expectations non-rationally, and the presence of these non-rational agents explains the significance of lags. Structural interpretation of this specification is hampered by the fact that it derives from an aggregation of non-rational agents that use a time-series model to forecast inflation with rational agents that adopt equation (1), even though it is misspecified under positive steady-state inflation.

15. For the shorter sample, a model with four lags of inflation fits U.S. inflation and inflation deviations best. Estimates of ω are 0.32 for inflation and 0.41 for inflation deviations, but neither estimate is statistically significant. However, estimates of ωA_4 are statistically significant.

inflation (and not the contemporaneous output gap), then the coefficient on the output gap in equation (4) becomes $(1 - \omega)g$ instead of g . For estimates of ω greater than zero, this would imply a larger value for the structural parameter g .

Table 4 presents results from estimation of the inflation expression that was obtained from the Taylor staggered-contracting framework. For $m > 2$, the number of free parameters to be estimated is m . However, free estimation resulted in very large standard errors on estimates of the coefficient G_0 that multiplies the contemporaneous output gap. Consequently, G_0 was restricted during estimation to equal the theoretical value that would obtain with equal distribution of contracts across m periods.¹⁶

The Taylor contracting specification results in comparable residual standard errors to the hybrid specifications. However, estimated coefficients are inconsistent with the staggered-contracts formulation for U.S. data. In particular, under the staggered-contracts formulation, G_i should be positive, reflecting that the proportions of outstanding contracts negotiated in $t-i$ should fall between zero and one (and sum to one over i). However, empirical estimates of G_2 and G_4 are statistically significant and negative. A consequence of the negative coefficient estimates is that the coefficients on a given lag/lead of inflation increase with the lag/lead order, rather than decrease, as predicted by the theory.

Empirical results for Canada are slightly more favourable towards the Taylor contracting specification. The specification with $m = 5$ fits the data best, both for inflation and inflation deviations. For this specification, estimates of G_4 are positive and significant, and estimates of G_2 and G_3 are insignificantly different from zero. P -values for tests of residual serial correlation are much higher and standard errors are more than 5 per cent smaller for $m = 5$ than for $m = 4$.

Table 5 contains results for estimates of a variant of the Fuhrer-Moore contracting specification. The difference between the specification estimated and the one described in section 1.3 is the treatment of the output gap. The specification that was estimated includes only the contemporaneous output gap. For U.S. inflation, standard errors are somewhat larger than those obtained for the Taylor contracting specification, and estimates of G_i are now insignificantly different from zero. For the case of $m = 5$, Q -statistics reject the presence of residual serial correlation for inflation deviations. Although estimates of coefficients on additional lags and leads of inflation

16. In other words, G_0 is restricted to be the theoretical value that would obtain if the outstanding contract proportions satisfy $h_i = 1/m$.

Table 4
Estimates under Taylor contracting

$$infl_t = c_1 + E_t infl_{t+1} + (G_2 + G_3 + G_4) infl_{t+2} + (G_3 + G_4) infl_{t+3} + G_4 infl_{t+4} \\ - (G_2 + G_3 + G_4) infl_{t-1} - (G_3 + G_4) infl_{t-2} - G_4 infl_{t-3} + \gamma G_0 y_t \\ + \gamma \left[\left(1 - \sum_{i=2}^4 G_i \right) (y_{t+1} + y_{t-1}) + G_2 (y_{t+2} + y_{t-2}) + G_3 (y_{t+3} + y_{t-3}) \right. \\ \left. + G_4 (y_{t+4} + y_{t-4}) \right] + resid_t$$

<i>m</i>	<i>g</i>	<i>G</i> ₂	<i>G</i> ₃	<i>G</i> ₄	<i>G</i> ₀	Q(4)	Q(8)	S.E.
United States—Inflation (<i>infl_t ≡ π_t</i>)								
3	0.041 (0.013)	-0.480 (0.067)			1	0.016	0.073	0.96
4	0.048 (0.014)	-0.360 (0.142)	-0.073 (0.075)		2/3	0.014	0.076	0.97
5	0.058 (0.015)	-0.414 (0.139)	0.257 (0.139)	-0.220 (0.080)	1/2	0.020	0.049	0.94
United States—Inflation deviations (<i>infl_t ≡ π̂_t</i>)								
3	0.041 (0.013)	-0.416 (0.061)			1	0.007	0.034	0.98
4	0.047 (0.015)	-0.291 (0.136)	-0.074 (0.071)		2/3	0.007	0.041	0.98
5	0.055 (0.015)	-0.330 (0.133)	0.213 (0.134)	-0.188 (0.075)	1/2	0.008	0.027	0.96
Canada—Inflation (<i>infl_t ≡ π_t</i>)								
3	0.169 (0.090)	-0.131 (0.210)			1	0.094	0.305	2.23
4	0.178 (0.104)	-0.490 (0.251)	0.315 (0.174)		2/3	0.117	0.286	2.09
5	0.262 (0.124)	-0.224 (0.252)	-0.223 (0.254)	0.446 (0.167)	1/2	0.551	0.608	1.96
Canada—Inflation deviations (<i>infl_t ≡ π̂_t</i>)								
3	0.169 (0.091)	-0.108 (0.215)			1	0.074	0.255	2.23
4	0.186 (0.108)	-0.452 (0.249)	0.316 (0.177)		2/3	0.099	0.243	2.10
5	0.277 (0.122)	-0.218 (0.251)	-0.177 (0.252)	0.426 (0.169)	1/2	0.717	0.672	1.98

Notes: Standard errors of coefficient estimates are provided in parentheses. Entries in columns Q(4) and Q(8) are *p*-values for *Q*-statistics for the null hypothesis of no serial correlation up to lags 4 and 8, respectively. The column labelled S.E. contains the regression standard error.

Table 5
Estimates under Fuhrer-Moore contracting

$$infl_t = c_1 + (1/2) \sum_{i=1}^{m-1} G_i (E_t infl_{t+i} + infl_{t-i}) + \gamma y_t + resid_t$$

$$G_1 = 1 - \sum_{i=2}^{m-1} G_i$$

<i>m</i>	γ	G_2	G_3	G_4	Q(4)	Q(8)	S.E.
United States—Inflation ($infl_t = \pi_t$)							
2	0.121 (0.040)				0.016	0.055	1.00
3	0.115 (0.041)	-0.086 (0.139)			0.019	0.064	1.00
4	0.125 (0.042)	-0.196 (0.179)	0.143 (0.146)		0.019	0.056	1.00
5	0.122 (0.043)	-0.197 (0.180)	0.135 (0.189)	0.007 (0.142)	0.020	0.059	1.00
United States—Inflation deviations ($infl_t = \hat{\pi}_t$)							
2	0.113 (0.040)				0.012	0.050	1.01
3	0.115 (0.041)	0.025 (0.136)			0.013	0.050	1.01
4	0.125 (0.042)	-0.105 (0.168)	0.188 (0.143)		0.018	0.061	1.01
5	0.131 (0.039)	-0.125 (0.169)	0.099 (0.176)	0.118 (0.135)	0.062	0.188	1.01
Canada—Inflation ($infl_t = \pi_t$)							
2	0.444 (0.226)				0.610	0.891	2.24
3	0.504 (0.229)	0.241 (0.261)			0.470	0.831	2.25
4	0.499 (0.227)	0.050 (0.297)	0.396 (0.305)		0.311	0.687	2.23
5	0.540 (0.226)	0.023 (0.294)	0.149 (0.347)	0.424 (0.293)	0.278	0.590	2.21
Canada—Inflation deviations ($infl_t = \hat{\pi}_t$)							
2	0.420 (0.228)				0.584	0.881	2.26
3	0.492 (0.230)	0.263 (0.259)			0.420	0.801	2.26
4	0.484 (0.227)	0.054 (0.292)	0.446 (0.304)		0.255	0.616	2.23
5	0.526 (0.224)	0.014 (0.288)	0.183 (0.339)	0.476 (0.291)	0.174	0.426	2.19

Notes: Standard errors of coefficient estimates are provided in parentheses. Entries in columns Q(4) and Q(8) are *p*-values for *Q*-statistics for the null hypothesis of no serial correlation up to lags 4 and 8, respectively. The column labelled S.E. contains the regression standard error.

are generally insignificant, regression standard errors are 10–15 per cent smaller than for the purely forward-looking specifications.¹⁷

The Fuhrer-Moore specification is less successful at explaining the behaviour of Canadian inflation and inflation deviations than the Taylor specification. Although estimates of coefficients on leads and lags of inflation are positive, they are not statistically significant, and for $m = 4$ and $m = 5$, standard errors are larger than for the Taylor specification, respectively, by 5 and 10 per cent.

Results from estimation of inflation dynamics from models with generalized frictions on price adjustment are provided in Table 6. These results may also be interpreted as a variant on the Taylor contracting specification. The Taylor specification can be obtained from the price-frictions model with $\beta = 1$ imposed and different constraints on how leads and lags of the output gap enter the expression.

For U.S. data, the standard errors from the price-frictions model are comparable with those obtained from the hybrid and Taylor specifications. As in the case of the Taylor specification, evidence of residual serial correlation remains. The slight improvement in fit obtained with the Taylor specification over the price-frictions specification is likely due to the inclusion of the additional leads and lags of the output gap (with the theoretical cross-coefficient restrictions imposed). Although not tabulated in this paper, when the Taylor specification was estimated with only the contemporaneous gap included, the fit was similar to that obtained from the price-frictions model.¹⁸

The advantage of the price-frictions approach over the Taylor contracting motivation is that the generalized-frictions formulation does not require the G_i s to be positive. For instance, if the frictions polynomial punishes changes in inflation, then $v(L)$ is proportional to $(1-L)^2 = 1 - 2L + L^2$, and the theoretical value for G_2 is $-1/3$ for $\beta = 1$. Given the negative estimates of the G_i coefficients for U.S. data, the price-frictions motivation seems to be a more appropriate interpretation of the results.

The Canadian data favour the price-frictions specification for $m = 3$, but the Taylor specification for $m = 5$. For $m = 3$, the Canadian data reject the implicit unit restriction on β in the Taylor specification, but for $m = 5$,

17. For the shorter sample, the Fuhrer-Moore specification with $m = 5$ obtained positive significant estimates of G_4 , smaller standard errors than the purely forward-looking specification, and large rejection probabilities for Q -statistics.

18. For the shorter sample, fit was comparable to the purely forward-looking specification, and coefficients on additional lags and leads of inflation (G_2, G_3, G_4) were insignificantly different from zero.

Table 6
Estimates under rational expectations
with frictions on price adjustment

$$infl_t = c_1 + \gamma y_t + \left((1 - G_2(1 - \beta) - G_3(1 - \beta^2) - G_4(1 - \beta^3)) \beta E_t infl_{t+1} \right. \\
+ (G_2 + G_3\beta + G_4\beta^2) \beta^2 E_t infl_{t+2} + (G_3 + G_4\beta) \beta^3 E_t infl_{t+3} + G_4\beta^3 E_t infl_{t+4} \\
\left. - (G_2 + G_3 + G_4) infl_{t-1} - (G_3 + G_4) infl_{t-2} - G_4 infl_{t-3} + resid_t \right)$$

<i>m</i>	γ	β	G_2	G_3	G_4	Q(4)	Q(8)	S.E.
United States—Inflation ($infl_t \equiv \pi_t$)								
3	0.141 (0.040)	0.720 (0.262)	-0.500 (0.056)			0.028	0.127	0.98
4	0.152 (0.042)	0.726 (0.266)	-0.384 (0.155)	-0.058 (0.074)		0.025	0.120	0.98
5	0.175 (0.044)	0.938 (0.069)	-0.412 (0.146)	0.253 (0.147)	-0.206 (0.082)	0.014	0.027	0.96
United States—Inflation deviations ($infl_t \equiv \tilde{\pi}_t$)								
3	0.120 (0.040)	0.622 (0.278)	-0.465 (0.067)			0.011	0.045	1.00
4	0.128 (0.041)	0.602 (0.270)	-0.317 (0.143)	-0.088 (0.074)		0.008	0.041	1.00
5	0.154 (0.041)	0.601 (0.246)	-0.406 (0.150)	0.250 (0.147)	-0.212 (0.082)	0.011	0.038	0.98
Canada—Inflation ($infl_t \equiv \pi_t$)								
3	0.573 (0.221)	0.215 (0.257)	-0.191 (0.165)			0.690	0.911	2.11
4	0.589 (0.222)	0.393 (0.371)	-0.345 (0.244)	0.161 (0.175)		0.706	0.885	2.11
5	0.707 (0.217)	0.932 (0.060)	-0.269 (0.231)	-0.043 (0.249)	0.368 (0.173)	0.386	0.441	2.06
Canada—Inflation deviations ($infl_t \equiv \tilde{\pi}_t$)								
3	0.586 (0.214)	-0.057 (0.255)	-0.141 (0.162)			0.695	0.943	2.03
4	0.601 (0.215)	0.079 (0.339)	-0.299 (0.234)	0.159 (0.174)		0.812	0.958	2.03
5	0.734 (0.219)	0.859 (0.137)	-0.252 (0.228)	-0.007 (0.246)	0.325 (0.182)	0.586	0.608	2.06

Notes: Standard errors of coefficient estimates are provided in parentheses. Entries in columns Q(4) and Q(8) are *p*-values for *Q*-statistics for the null hypothesis of no serial correlation up to lags 4 and 8, respectively. The column labelled S.E. contains the regression standard error.

the estimate of β is insignificantly different from one and the information in the additional lags and leads of the output gap reduces the standard error of the Taylor specification relative to the price-frictions specification, although the latter specification also fits the data reasonably well.

The last specification considered is an expression for inflation under frictions on inflation adjustment. The inflation-frictions specification resembles the Fuhrer-Moore contracting specification, but with β unconstrained. Results are reported in Table 7. Standard errors are very similar to those in Table 5. This is not surprising since in most cases, the null hypothesis that $\beta = 1$ is not rejected by the data. One notable difference for the United States is that evidence of residual serial correlation is largely gone for $m = 4$ and $m = 5$.¹⁹ For Canadian data, as estimation routines were not converging for $m > 2$, results are presented only for the case $m = 2$.

Overall, inflation dynamics seem to be better captured by models that include lags and leads of inflation rather than by specifications that are only forward-looking. In addition, lags and leads of the output gap in the Taylor specification appeared to help explain inflation dynamics. However, the data did not strongly support any one model. Estimates of backward-looking behaviour by a fraction of agents in the hybrid model were contradictory. For U.S. data, coefficient estimates in the Taylor model were inconsistent with positive contract-distribution coefficients, and residual serial correlation was evident for Taylor and price-frictions specifications. Overall, the evidence appeared most favourable for the Fuhrer-Moore and inflation-frictions specifications. For larger m , these specifications had cleaner residuals and coefficient estimates that were not inconsistent or contradictory with the theory, although standard errors were slightly larger for these specifications than for some of the others.²⁰

For Canadian data, the Taylor and price-frictions specifications for $m = 5$ seemed to be favoured by the data with the smallest standard errors obtained for the Taylor specification. With these specifications, Q -statistics provided no evidence of residual serial correlation. Restrictions imposed by the Fuhrer-Moore contracting specification and the inflation-frictions specification appeared inconsistent with Canadian data, since standard errors for these specifications were roughly 5 per cent larger than for hybrid models and 10 per cent larger than for Taylor and price-frictions specifications.

19. For the shorter sample, all aspects of the estimation of the inflation deviations specification with $m = 5$ were similar to those obtained for the Fuhrer-Moore specification with $m = 5$.

20. Similar arguments favoured the Fuhrer-Moore and inflation-frictions specifications for the shorter sample.

Table 7
Estimates under rational expectations
with frictions on inflation adjustment

$\text{infl}_t = c_1 + \gamma y_t + \text{resid}_t$ $+ [G_1(\beta E_t \text{infl}_{t+1} + \text{infl}_{t-1}) + G_2(\beta^2 E_t \text{infl}_{t+2} + \text{infl}_{t-2})] / [1 + G_1\beta + G_2\beta^2 + G_3\beta^3 + G_4\beta^4]$ $+ [G_3(\beta^3 E_t \text{infl}_{t+3} + \text{infl}_{t-3}) + G_4(\beta^4 E_t \text{infl}_{t+4} + \text{infl}_{t-4})] / [1 + G_1\beta + G_2\beta^2 + G_3\beta^3 + G_4\beta^4]$ $G_i = 1 - \sum_{j=2}^{m-i} G_j$								
<i>m</i>	γ	β	G_2	G_3	G_4	Q(4)	Q(8)	S.E.
United States—Inflation ($\text{infl}_t \equiv \pi_t$)								
2	0.120 (0.041)	0.928 (0.294)				0.020	0.076	1.00
3	0.118 (0.041)	1.887 (0.645)	-0.221 (0.087)			0.008	0.021	1.00
4	0.137 (0.042)	0.688 (0.210)	-0.142 (0.162)	0.249 (0.130)		0.103	0.312	1.00
5	0.145 (0.044)	0.650 (0.201)	-0.133 (0.157)	0.173 (0.157)	0.109 (0.130)	0.330	0.683	1.00
United States—Inflation deviations ($\text{infl}_t \equiv \hat{\pi}_t$)								
2	0.116 (0.041)	1.192 (0.346)				0.009	0.026	1.01
3	0.119 (0.041)	2.070 (0.735)	-0.166 (0.074)			0.004	0.009	1.01
4	0.130 (0.042)	0.823 (0.191)	-0.077 (0.159)	0.248 (0.134)		0.041	0.149	1.01
5	0.144 (0.043)	0.741 (0.160)	-0.074 (0.149)	0.122 (0.150)	0.207 (0.124)	0.604	0.876	1.00
Canada—Inflation ($\text{infl}_t \equiv \pi_t$)								
2	0.533 (0.233)	2.819 (2.511)				0.468	0.803	2.22
Canada—Inflation deviations ($\text{infl}_t \equiv \hat{\pi}_t$)								
2	0.521 (0.236)	3.042 (2.873)				0.415	0.760	2.23

Notes: Standard errors of coefficient estimates are provided in parentheses. Entries in columns Q(4) and Q(8) are *p*-values for *Q*-statistics for the null hypothesis of no serial correlation up to lags 4 and 8, respectively. The column labelled S.E. contains the regression standard error.

The additional information attributable to the restricted lags and leads of the output gap in the Taylor specifications suggests that alternative specifications of the frictions polynomial may improve the performance of this specification. One possibility is to generalize the adjustment-cost polynomial to account for costs to a producer associated with altering the output rate. Such a generalization fits within the vector rational error-correction (VREC) framework developed by Kozicki and Tinsley (1999a). A model of price-setting described by McCallum and Nelson (1999) may be taken as an example of a restricted version of the VREC framework. In their model, deviations of prices from their no-friction optimal level are due to quadratic costs associated with adjusting output rates, but not prices.

3 Implications for Monetary Policy

The results of the previous section suggest several lessons for monetary policy-makers. First, historical shifts in the nominal anchor for expectations provide evidence against the theory that a long-run trade-off exists between inflation and economic activity. Second, the increased use of structural macroeconomic models should reduce the likelihood that low inflation persistence is misinterpreted as signalling that a long-run trade-off exists between inflation and economic activity. Third, the results suggest that the introduction of an explicit inflation-targeting regime in Canada resulted in increased credibility for low-inflation goals.

Some of the persistence of Canadian and U.S. inflation can be associated with historical shifts in the anchor of long-run inflation expectations. In both countries, inflation persistence was lower after accounting for shifts in the nominal anchor, and inflation persistence in the 1990s, a period of relatively low and stable inflation, was almost non-existent. Results suggesting that the nominal anchor has not been constant provide evidence supporting the Friedman (1968) and Phelps (1967) critiques of Phillips curve representations that embody a long-run trade-off between inflation and economic activity. The fact that the nominal anchor has shifted historically should be taken as a warning to policy-makers that it may shift again if policy actions do not continue to support low and stable inflation. In other words, as noted by Cogley and Sargent (2001) and Taylor (1998), while persistence has declined, it would not be appropriate to revert to the view that a long-run trade-off exists between inflation and economic activity.

One factor that should help reduce the likelihood that beliefs in a long-run inflation-output trade-off will re-emerge, is the increased emphasis on structural macroeconomic models in policy evaluation. Of course, not all models are structural and some structural models incorporate unrealistic assumptions. As noted in this paper, purely forward-looking models

generally fail at explaining the lag dynamics of inflation. Modifications to price-setting behaviour that result in inflation expressions with additional lags and leads of inflation improve the ability of models to explain the lag dynamics of inflation. Recognizing this potential improvement, some policy models already incorporate such modified inflation expressions.

Few models, however, admit a shifting anchor for long-run inflation expectations.²¹ Policy models that exclude nominal anchor shifts are taking a strong view that the goals of policy are fully known, fully credible, and do not change. By contrast, the empirical results of this paper suggest that the nominal anchor has shifted and that there have been episodes when policy was less than fully credible. Thus, introducing the potential for nominal anchor shifts and imperfect policy credibility would be an important improvement for models to be used for evaluating monetary policy alternatives.

While the empirical results suggest that both Canada and the United States experienced historical shifts in their nominal anchors, the experience of the two countries differed somewhat in the 1990s. Since 1995, long-horizon inflation expectations for Canada have fallen close to the midpoint of the inflation-control target range, which is also close to the central tendency of inflation. By contrast, in the United States, although inflation was relatively low and stable for most of the 1990s, long-horizon inflation expectations tended to be higher than measured inflation. The announcement of an inflation target range in Canada helped reduce public uncertainty about the inflation goal of policy. Credibility of the inflation target likely increased relatively quickly as subsequent policy actions were taken to be consistent with the announced inflation-targeting regime.

Conclusions

This paper examined four potential sources of lag dynamics in inflation: non-rational behaviour, staggered contracting, frictions on price adjustment, and shifts in the long-run inflation anchor of agent expectations. The empirical evidence suggests that shifts in the long-run inflation anchor of agent expectations have contributed importantly to observed persistence in U.S. and Canadian inflation. Such shifts, however, don't appear to explain all of the historical persistence in inflation. Models of inflation and deviations of inflation from the nominal anchor, which admit additional lags and leads, explain the historical behaviour of inflation better than purely forward-looking models. Interestingly, structural models derived from

21. The FRB/US model of the Federal Reserve Board of Governors is one exception (Brayton, Levin, Tryon, and Williams 1997).

assumptions about staggered contracts or frictions associated with price adjustment are better able to explain inflation dynamics than hybrid models that assume a fraction of agents form expectations non-rationally.

The empirical evidence suggests that shifts in the nominal anchor, less than full policy credibility, and inflation stickiness have all been important features of the historical behaviour of inflation. Although many policy models incorporate some form of inflation stickiness, few currently allow shifts in the nominal anchor and accommodate the potential for less than full policy credibility. These are important features, particularly for models to be used for monetary policy analysis, that one hopes will be incorporated into the next generation of policy models.

Appendix

This Appendix provides a derivation for a New Keynesian Phillips curve with a non-zero steady-state inflation rate. Similar derivations are provided in Ascari (2002) and Bakhshi, Burriel-Llombart, Khan, and Rudolf (2002). The expression for inflation derived here is consistent with that in Bakhshi et al. under a common-factor market assumption.

A retail distributor combines the differentiated output of a continuum of monopolistically competitive firms, $Y_{i,t}$, into a composite product, Y_t , with price elasticity of demand, θ :

$$Y_t = \left[\int_0^1 Y_{i,t}^{\frac{\theta-1}{\theta}} di \right]^{\frac{\theta}{\theta-1}}. \quad (\text{A1})$$

The retailer sells this composite product directly to households. Maximizing retailer profits implies that the retailer's demand for the i th firm's output is:

$$Y_{i,t} = \left[\frac{P_{i,t}}{P_t} \right]^{-\theta} Y_t, \quad (\text{A2})$$

where $P_{i,t}$ is the price of firm i output, and P_t is an index of goods prices at date t . The aggregate price index is defined as:

$$P_t = \left[\int_0^1 P_{i,t}^{1-\theta} di \right]^{\frac{1}{1-\theta}}. \quad (\text{A3})$$

In the absence of constraints on price adjustment, each firm chooses the optimal price level, $P_{i,t}^*$, to maximize current period real profits, $\Pi_{i,t}$, where

$$\Pi_{i,t} = \left[\frac{P_{i,t}}{P_t} - \frac{W_t}{P_t Z_t} \right] \left[\frac{P_{i,t}}{P_t} \right]^{-\theta} Y_t, \quad (\text{A4})$$

W_t are nominal wages paid to workers, and Z_t is the labour-augmenting productivity process. Profit maximization implies the optimal relative price, $(P_{i,t}/P_t)^*$, satisfies

$$\left(\frac{P_{i,t}}{P_t} \right)^* = \mu \frac{W_t}{P_t Z_t}, \quad (\text{A5})$$

where $\mu = (1 - 1/\theta)^{-1}$ is a markup and $W_t/(P_t Z_t)$ is real marginal cost.

Under Calvo (1983) pricing, price adjustment is constrained. Each period, a firm is allowed to change its price with probability $(1 - \lambda)$. Firms choose their optimal reset price according to

$$P_{r,t} = \arg \max_{\{P_{t,t}\}} \left\{ E_t(1 - \lambda) \sum_{j=0}^{\infty} \lambda^j R_{t,t+j} \left[\frac{P_{t,t}}{P_{t+j}} - \frac{W_{t+j}}{P_{t+j} Z_{t+j}} \right] \left[\frac{P_{t,t}}{P_{t+j}} \right]^{-\theta} Y_{t+j} \right\}, \quad (\text{A6})$$

where $R_{t,t+j}$ is a j -period discount rate. After algebraic manipulation, it is easy to show that the optimal relative reset price, $P_{r,t}/P_t$, satisfies

$$\frac{P_{r,t}}{P_t} = \sum_{j=0}^{\infty} w_{jt} \left(\frac{P_{t,t+j}}{P_{t+j}} \right)^{\frac{\theta}{1-\theta}} \prod_{k=1}^j \Pi_{t+k}, \quad (\text{A7})$$

where $\Pi_{t+k} = P_{t+k}/P_{t+k-1}$ is the gross inflation rate from $t+k-1$ to $t+k$, and the expression for the weights can be simplified to

$$w_{jt} = \frac{(\lambda\beta)^j \left(\prod_{k=1}^j \Pi_{t+k} \right)^{\theta-1}}{\sum_{j=0}^{\infty} (\lambda\beta)^j \left(\prod_{k=1}^j \Pi_{t+k} \right)^{\theta-1}} \quad (\text{A8})$$

under additional assumptions.¹

With Calvo-type constraints on price adjustment, the aggregate price index evolves according to

$$P_t = \left[\lambda P_{t-1}^{1-\theta} + (1 - \lambda) P_{r,t}^{1-\theta} \right]^{\frac{1}{1-\theta}}. \quad (\text{A9})$$

1. One set of assumptions that generates this convenient simplification is that the discount rate, $R_{t,t+j}$, equals $\beta u'(C_{t+j})/u'(C_t)$ for marginal utility of consumption $u'(C)$ and utility discount factor β , households maximize discounted utility with $u(C) = \log(C)$, and consumption equals the composite product in equilibrium.

Rearranging this expression, the optimal relative reset price is related to aggregate inflation,

$$\frac{P_{r,t}}{P_t} = \left[\frac{1 - \lambda \Pi_t^{\theta-1}}{1 - \lambda} \right]^{\frac{1}{1-\theta}} \quad (\text{A10})$$

The higher is aggregate inflation, the higher is the optimal relative reset price. Intuitively, with higher aggregate inflation, the optimal reset price is set higher relative to the aggregate price level in t because a firm's reset price may not be adjusted for several periods even though the aggregate price level will continue to increase.

To account for a non-zero steady-state inflation rate, linearize equations (A10) and (A7) in terms of per cent deviations of $(P_{r,t}/P_t)$, $(P_{i,t}/P_t)^*$, and Π_t from their steady-state values. In this notation, let $\bar{\pi}$ represent the steady-state inflation rate, so that $1 + \bar{\pi}$ is the steady-state gross inflation rate. An expression similar to equation (1) also involves relating the percentage deviation of $(P_{i,t}/P_t)^*$ from its steady state to the percentage deviation of Y_t from its steady state, as in McCallum and Nelson (1999) and Kozicki and Tinsley (2002). Let $\hat{\pi}_t$ denote the percentage deviation of gross inflation from $1 + \bar{\pi}$, y_t denote the percentage deviation of output, Y_t , from potential, and γ^* represent the factor of proportionality between percentage deviations of $(P_{i,t}/P_t)^*$ from steady state and y_t . The resultant expression for inflation is:

$$\hat{\pi}_t = b E_t \hat{\pi}_{t+1} + g y_t + c (1 - \lambda \beta (1 + \bar{\pi})^{\theta-1}) \sum_{j=1}^{\infty} \left(\lambda \beta (1 + \bar{\pi})^{\theta-1} \right)^j \sum_{k=1}^j E_t \hat{\pi}_{t+1+k} + \varepsilon_t^*, \quad (\text{A11})$$

where

$$\begin{aligned} b &= \beta \left[\lambda (1 + \bar{\pi})^{\theta} + (1 - \lambda (1 + \bar{\pi})^{\theta-1}) (\theta (1 + \bar{\pi}) + (1 - \theta)) \right] \\ c &= \beta \bar{\pi} (\theta - 1) (1 - \lambda (1 + \bar{\pi})^{\theta-1}) \\ g &= \left[\gamma^* (1 - \lambda (1 + \bar{\pi})^{\theta-1}) (1 - \beta \lambda (1 + \bar{\pi})^{\theta}) \right] / \left[\lambda (1 + \bar{\pi})^{\theta-1} \right] \quad (\text{A12}) \end{aligned}$$

are non-linear functions of the structural parameters β , $\bar{\pi}$, θ , and λ ; and ε_t^* is an error term. For a positive steady-state inflation rate, $\bar{\pi}$ will be greater than zero. When steady-state inflation is equal to zero, the model simplifies to the benchmark model in equation (1) with $b = \beta$, $c = 0$, and $g = \gamma^*(1 - \lambda)(1 - \beta\lambda)/\lambda \equiv \gamma$.²

Table A1 shows ranges of coefficient estimates for different values of structural parameters. Values for β and λ are in the range of estimates obtained by Galí and Gertler (1999). Values of $\bar{\pi}$ equal to .01 and .005 correspond to steady-state inflation rates of about 4 per cent and 2 per cent, respectively, expressed at an annual rate. Values for θ are within the range suggested by the literature, with θ equal to 11, 5, and 2.67 corresponding to markups (μ) of 1.10, 1.25, and 1.60, respectively. Basu and Fernald (1997) estimated the average value of the markup to be 1.16 for the entire private economy. Cooper and Haltiwanger (2000) estimated the markup for manufacturing to be 1.27. Domowitz, Hubbard, and Petersen (1988) estimated the markup to be 1.58. In work on magazine prices, Willis (2000) estimated the markup to be 1.75. Hall (1988) estimated the markup to be over 2. As the markup increases, the implied value of θ decreases (and the differences between b and β , g/γ^* and γ/γ^* , and c and zero shrink). As noted earlier, as the anchor of inflation expectations approaches zero, the coefficients approach those for the benchmark expression. The limiting results are summarized in the top row of the table.

The expression in equation (2) is an approximation to the expression in equation (A11). Compared with the approximation, equation (A11) has an additional term that includes discounted expected inflation deviations. The analysis in the main body of this paper uses the simpler approximating expression, because the empirical relevance of the discounted sum of expected inflation deviations is likely to be small. However, the relevance of the term also depends on the degree of inflation persistence. The intuition follows by substituting for expected inflation in the discounted sum, forecasts based on the following simple reduced-form representation of inflation, $E_t \pi_{t+k} = \rho^{k+1} \pi_{t-1}$. In this case, the discounted sum simplifies to:

2. When $\bar{\pi} = 0$, the expression for g/γ^* matches that derived, for example, by Galí and Gertler (1999).

Table A1

Coefficient estimates in benchmark and approximating models

θ	β	λ	$\bar{\pi}$	b	g/γ^*	γ/γ^*	c	coef. on $\hat{\pi}_{t-1}$	
								$\rho = 0.9$	$\rho = 0.5$
			0	β	γ/γ^*		0	0	0
11	1	0.8	0.01	1.022	0.014	0.050	0.0116	0.041	0.005
11	1	0.8	0.005	1.013	0.029	0.050	0.0080	0.022	0.003
11	1	0.75	0.01	1.027	0.034	0.083	0.0172	0.045	0.006
11	1	0.75	0.005	1.016	0.056	0.083	0.0106	0.023	0.003
11	0.8	0.8	0.01	0.817	0.038	0.090	0.0093	0.015	0.003
11	0.8	0.8	0.005	0.810	0.061	0.090	0.0064	0.009	0.002
11	0.8	0.75	0.01	0.822	0.069	0.133	0.0137	0.018	0.003
11	0.8	0.75	0.005	0.813	0.098	0.133	0.0085	0.010	0.002
5	1	0.8	0.01	1.017	0.032	0.050	0.0067	0.018	0.002
5	1	0.8	0.005	1.009	0.041	0.050	0.0037	0.009	0.001
5	1	0.75	0.01	1.019	0.060	0.083	0.0088	0.019	0.003
5	1	0.75	0.005	1.010	0.071	0.083	0.0047	0.009	0.002
5	0.8	0.8	0.01	0.813	0.066	0.090	0.0054	0.007	0.001
5	0.8	0.8	0.005	0.807	0.078	0.090	0.0029	0.004	0.001
5	0.8	0.75	0.01	0.815	0.104	0.133	0.0070	0.008	0.002
5	0.8	0.75	0.005	0.808	0.118	0.133	0.0038	0.004	0.001
2.67	1	0.8	0.01	1.013	0.041	0.050	0.0031	0.008	0.001
2.67	1	0.8	0.005	1.007	0.045	0.050	0.0016	0.004	0.001
2.67	1	0.75	0.01	1.014	0.072	0.083	0.0040	0.008	0.001
2.67	1	0.75	0.005	1.007	0.077	0.083	0.0020	0.004	0.001
2.67	0.8	0.8	0.01	0.811	0.079	0.090	0.0025	0.003	0.001
2.67	0.8	0.8	0.005	0.805	0.084	0.090	0.0013	0.002	0.000
2.67	0.8	0.75	0.01	0.811	0.120	0.133	0.0032	0.004	0.001
2.67	0.8	0.75	0.005	0.806	0.126	0.133	0.0016	0.002	0.000

$$\begin{aligned}
& \left(1 - \lambda\beta(1 + \pi)^{\theta-1}\right) \sum_{j=1}^{\infty} \left(\lambda\beta(1 + \bar{\pi})^{\theta-1}\right)^j \sum_{k=1}^j E_t \hat{\pi}_{t+1+k} \\
&= \left[\left(1 - \lambda\beta(1 + \bar{\pi})^{\theta-1}\right) \sum_{j=1}^{\infty} \left(\lambda\beta(1 + \bar{\pi})^{\theta-1}\right)^j \rho^2 \frac{(1 - \rho^j)}{(1 - \rho)} \right] \hat{\pi}_{t-1} \\
&= \lambda\beta(1 + \bar{\pi})^{\theta-1} \frac{\rho^2}{(1 - \rho)} \left[1 - \frac{\rho(1 - \lambda\beta(1 + \bar{\pi})^{\theta-1})}{1 - \lambda\beta\rho(1 + \bar{\pi})^{\theta-1}} \right] \hat{\pi}_{t-1}. \quad (A13)
\end{aligned}$$

As shown in Table A1, for various degrees of inflation persistence, the coefficient on this term (in the column labelled "coef. on $\hat{\pi}_{t-1}$ ") is two to three orders of magnitude smaller than the coefficient on expected inflation (in the column labelled " b "). Consequently, the discounted sum is merged into the error term in equation (2),

$$\varepsilon_t = \varepsilon_t^* + c \left(1 - \lambda \beta (1 + \bar{\pi})^{\theta-1} \right) \sum_{j=1}^{\infty} \left(\lambda \beta (1 + \bar{\pi})^{\theta-1} \right)^j \sum_{k=1}^j E_t \hat{\pi}_{t+1+k}. \quad (\text{A14})$$

With this approximation, the error term ε_t in equation (2) will be correlated with the explanatory variables, and estimation procedures that do not account for this correlation will induce bias into coefficient estimates. However, the size of the bias will generally be small as long as c is small.

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Discussion

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Introduction

New Keynesian Phillips curves are widely used to assess the effects of macroeconomic policies on inflation. The basic specification of this class of Phillips curve expresses current inflation as a linear function of expected future inflation and current output gap.

Kozicki and Tinsley (2003) argue that the basic specification predicts that inflation is not sticky, given that it excludes lagged inflation. The authors also state that this prediction is controversial, since the Canadian and U.S. empirical evidence reveals that inflation is persistent.

For this reason, Kozicki and Tinsley analyze alternative sources of the lag dynamics of inflation. These alternative specifications reflect non-rational behaviour, staggered contracts, and frictions on price adjustment. These variants enrich the basic specification by including leads and lags of expected inflation and output gap. Furthermore, the basic and alternative specifications are estimated by first using the inflation rate and then the deviation of inflation from the nominal anchor. This last measure reduces to the demeaned inflation rate when there is no shift in agents' expectations of inflation targets.

The authors mainly test the null hypothesis of no serial correlation of the residuals to determine which specifications best describe the lag dynamics of inflation. Unfortunately, no specification is statistically rejected when this econometric procedure is applied for the Canadian case. Only the basic specification is clearly rejected for the U.S. case.

This discussion will first show that the basic specification can conceptually predict sticky inflation, so that it can potentially capture the actual inflation persistence. Second, alternative econometric methods are applied to better describe inflation dynamics and discriminate among the various specifications. Third, the sensitivity of the empirical results to the constructed inflation and output-gap measures and to the selected subsamples is discussed. Most of these comments are numerically illustrated by focusing on the basic specification for the Canadian experience. In that way, this discussion explores the basic source of the lag dynamics of Canadian inflation.

1 Inflation Dynamics

Consider a simple environment where agents face a number of frictions, such that they slowly adjust their prices to various target levels. This case is described by the following intertemporal planning problem:

$$\max_{p_t} E_t \sum_{j=0}^{\infty} \beta^j [(p_{t+j} - p_{t+j}^*)^2 + (p_{t+j} - p_{t+j-1})^2], \quad (1)$$

$$\text{s.t. } (p_t^* - p_t) = \gamma y_t.$$

The variable p_t is the logarithm of the price index in period t , p_t^* is the logarithm of the target index, y_t is the output gap, and E_t is the conditional expectation operator. Also, $0 < \beta < 1$ is the subjective discount factor, whereas $\gamma > 0$ reflects the intuition that the target price increases when the output gap increases.

The first-order condition for equation (1) yields the Euler equation:

$$\pi_t = \beta E_t \pi_{t+1} + \gamma y_t, \quad (2)$$

where $\pi_t = (p_t - p_{t-1})$ is the inflation rate. Equation (2) corresponds to the basic specification of the New Keynesian Phillips curves.

Kozicki and Tinsley use equation (2) to document the inflation dynamics predicted by the basic specification. They argue that because this specification omits lagged inflation, it cannot generate the persistence observed in actual inflation.

However, the basic specification can, in fact, produce sticky inflation. This notion is illustrated by first solving forward equation (2) to yield the decision rule:

$$\pi_t = \gamma E_t \sum_{j=0}^{\infty} \beta^j y_{t+j}, \quad (3)$$

where the inflation rate corresponds to the variable of interest and the output gap is the forcing variable.

Then, consider the unrestricted first-order vector-autoregressive (VAR) process:

$$X_t = \Phi X_{t-1} + U_t, \quad (4)$$

where $X_t = (y_t, \pi_t)'$. The process (4) states that inflation Granger-causes the output gap. Such feedback implies that agents can improve their forecasts of the future output gap by taking into account the history of inflation. This captures a rich dynamic often found in the data for forcing variables, termed external dynamics (Cogley and Nason 1995). Furthermore, external dynamics are consistent with the case where the true law of motion for the output gap corresponds to an unrestricted VAR involving both the forcing variable and an exogenous hidden variable (Boileau and Normandin 2002). For these reasons, the unrestricted VAR (4) seems appropriate to construct the agents' expectations of future output gap.

Finally, substituting the constructed expectations in the decision rule yields the restricted first-order VAR:

$$X_t = \Theta X_{t-1} + V_t. \quad (5)$$

The process (5) imposes the cross-equation restrictions:

$$e_1' \Theta = \gamma e_1' (I - \beta \Phi)^{-1} \Phi \text{ and } e_2' V = \gamma e_1' (I - \beta \Phi)^{-1} U_t,$$

where $e_1' = (1, 0)'$, $e_2' = (0, 1)'$, and I is the identity matrix. These restrictions reflect the structure of the basic specification (2).

Importantly, the notion that inflation contains relevant information to forecast the future output gap is reflected in the restricted VAR (5) by feedback from lagged inflation to current inflation. Because this process includes lagged inflation, it can potentially generate the persistence observed in actual inflation rates. Accordingly, the basic specification can predict sticky inflation.

This result can be generalized by amending equations (4) and (5) to consider p -order unrestricted and restricted VARs. In this case, current inflation is

predicted to be related to the first p lagged values of inflation. Again, this can yield to a substantial inflation persistence.

2 Econometric Procedure

Kozicki and Tinsley apply an econometric procedure that can be summarized as follows. They resort to survey data on inflation expectations to approximate expected future inflation. Using this proxy, they estimate the various specifications by using instrumental variable methods. They then compute the Q -statistics to test the null hypothesis of no serial correlation of the residuals. The non-rejection of the null is interpreted as evidence that the lag dynamics of inflation are appropriately described.

For the Canadian economy, the authors cannot reject the null for the basic specification as well as for each alternative specification. This indicates that every specification adequately characterizes the lag dynamics of inflation. Hence, it becomes difficult to discriminate among the various specifications. Put differently, this suggests that the test is weak.

To circumvent this problem, an alternative econometric procedure is illustrated for the basic specification. In this procedure, an unrestricted p -order VAR like equation (4) is estimated by ordinary least squares (OLS), and a restricted p -order VAR like equation (5) is constructed. These processes are used to design several tests. First, the empirical autocorrelations of inflation computed from the unrestricted VAR or from the data are statistically compared with the predicted autocorrelations generated from the restricted VAR. This provides a direct assessment of inflation persistence. Second, the empirical impulse responses of inflation to an output-gap shock induced by the unrestricted VAR are compared with the predicted responses obtained from the restricted VAR. This yields information on inflation dynamics. Third, the cross-equation restrictions $e_2'\Theta = \gamma e_1'(I - \beta\Phi)^{-1}\Phi$ are tested. The non-rejection of the null hypothesis is clearly interpreted as evidence that the lag dynamics of inflation are appropriately described by the basic specification.

These tests are applied for the Canadian economy. The quarterly data cover the 1962Q1 to 2001Q4 period and the 1992Q1 to 2001Q4 subperiod. The demeaned inflation rate is computed from last-month, yearly growth of the total CPI index. The output gap is measured from the percentage deviation of the real GDP to its HP-filter component. Note that Kozicki and Tinsley perform their analysis by using similar data over a period corresponding to our subsample. Moreover, for this subsample, it is reasonable to assume that the policy target for inflation is time-invariant and widely known. In this

context, the demeaned inflation rate corresponds to the deviation of inflation from the nominal anchor.

For the full sample, the Akaike and Schwarz criteria indicate that the appropriate lag structure for the unrestricted VAR is $p = 2$. The p -value for the $\chi^2(2)$ statistic associated with the joint test of zero feedback from lagged inflation to the current output gap is 0.011. This Granger-causality test implies that inflation contains useful additional information for forecasting the output gap. Likewise, for the subsample, the relevant lag structure is $p = 2$, and the p -value is 0.032. For the full sample and the subsample, the OLS estimates of the unrestricted VARs and the calibrated values $\beta = 0.996$ and $\gamma = 0.600$ are used to construct the coefficients of the restricted VARs. Note that the discount factor, β , is set to the standard value for quarterly data. The parameter γ is fixed to the estimated values reported in Kozicki and Tinsley.

Table 1 presents the first-, second-, and fourth-order autocorrelations of inflation found in the data and induced by the restricted VARs. This table also reports the p -values for the $\chi^2(1)$ statistics associated with the test that the difference between empirical and predicted autocorrelations is zero, where these statistics account for the uncertainty in estimated parameters of the unrestricted VARs. For the full sample, the empirical autocorrelations reveal that actual inflation is very sticky. The predicted autocorrelations also imply that inflation is considerably persistent, but to a lesser extent than that observed in the data. Formally, the empirical and predicted first-order autocorrelations are not statistically different, but the second- and fourth-order autocorrelations are significantly different. For the subsample, similar results hold. Hence, although the basic specification (2) numerically generates highly autocorrelated inflation, it cannot statistically replicate the substantial degree of persistence in actual inflation.

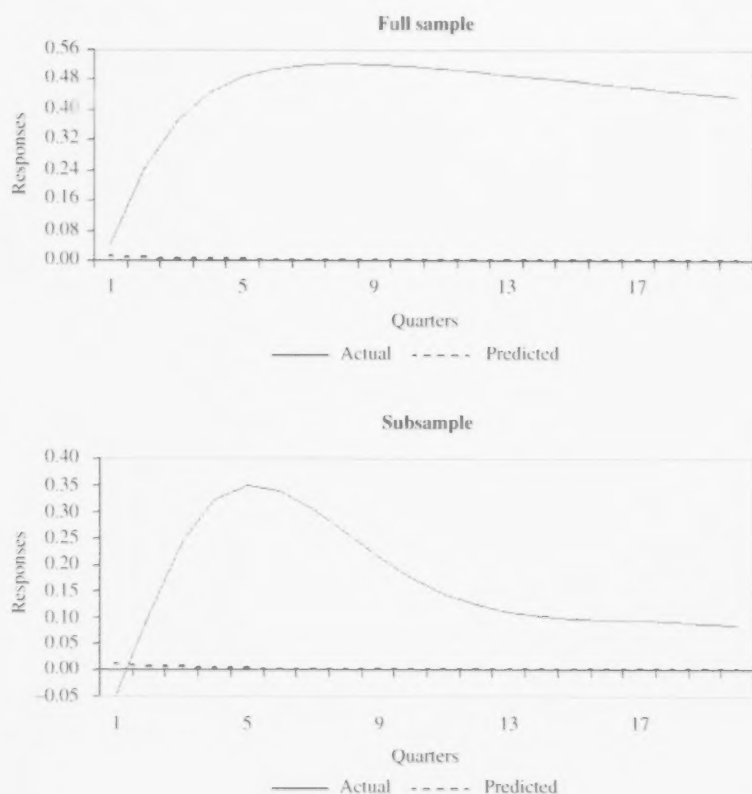
Figure 1 displays the empirical and predicted dynamic responses of inflation following a one standard-deviation output-gap shock. For the full sample, the empirical response computed from the unrestricted VAR is initially positive, increases sharply to reach a peak after eight quarters, and then declines slowly. In contrast, the predicted response obtained from the restricted VAR is close to zero for all quarters. For the subsample, similar results hold. Thus, these findings highlight that the basic specification considerably underpredicts the inflation dynamic adjustments.

Finally, the cross-equation restrictions are tested. For the full sample, the p -value for the $\chi^2(8)$ statistic is 0.000. For the subsample, an identical result is obtained. Therefore, the results clearly indicate that the basic specification provides an incorrect characterization of the lag dynamics of inflation.

Table 1
Autocorrelations of inflation

	Full Sample		
	1	2	4
Empirical	0.961	0.917	0.811
Predicted	0.589	0.404	0.164
P-value	0.267	0.010	0.000
	Subsample		
	1	2	4
Empirical	0.694	0.396	-0.053
Predicted	0.483	0.342	0.087
P-value	0.737	0.336	0.001

Figure 1



Importantly, the findings reported above sharply contrast with the results found by applying the econometric procedure followed by Kozicki and Tinsley. Remember that this procedure relies mainly on testing the null hypothesis of no serial correlation in residuals. Empirically, this test never leads to the statistical rejection of the basic and alternative specifications.

3 Data

As mentioned, Kozicki and Tinsley use survey data on inflation expectations. For the Canadian case, the available data are quarterly forecasts of total CPI inflation over the post-1990 period. These data dictate which inflation measure, observation frequency, and sample period are used.

However, the selection of the measure may have important consequences for the assessment of the basic and alternative specifications. For example, it is well known that the inflation measures based on the GDP deflator and the CPI index do not conceptually reveal the same information, and as such may not exhibit similar dynamic properties. Furthermore, even the inflation measures based on the different variants of the CPI may not display the same degree of persistence. In particular, the total CPI inflation is expected to be less smooth than the core inflation, because the latter measure excludes some of the most volatile components. The core inflation seems appealing, given that this measure is used by the Bank of Canada to define the inflation targets.

The selection of the frequency may also be of interest. For example, quarterly data on inflation are presumably stickier than monthly inflation. Monthly data are likely to be more useful, given that inflation can be better monitored at this frequency by the Bank of Canada.

Moreover, the selection of the sample is important. In particular, the inflation persistence is greater for the full sample (1962Q1 to 2001Q4) than for the subsample (1992Q1 to 2001Q4). It is tempting to argue that the non-rejection of the basic and alternative specifications for the subsample occurs because it is easier to generate uncorrelated residuals when inflation is less persistent. As shown previously, however, the basic specification is clearly rejected even for the subsample, when alternative econometric tests are performed.

In brief, the selection of the inflation measure, observation frequency, and sample period is likely to affect the test results about the validity of the basic and alternative specifications. Therefore, it would appear important to document the sensitivity of the results by using several measures, frequencies, and periods. Unfortunately, the econometric procedure relying on survey data on inflation expectations confines the analysis to a unique

measure, a single frequency, and a short sample. The alternative econometric method proposed above does not involve survey data, such that a sensitivity analysis can be performed.

Kozicki and Tinsley also measure the Canadian output gap as the percentage deviation of the real GDP to its HP-filter component. Strictly speaking, this measure is a proxy for marginal costs. However, the output gap is conceptually affected by both aggregate demand and supply. Furthermore, the ex post revisions of the measure of output gap are evaluated to be of the same order of magnitude as the estimated output gap itself. This problem is mainly due to the pervasive unreliability of end-of-sample estimates of the HP trend (Orphanides and van Norden 2002).

Conclusions

Kozicki and Tinsley's analysis certainly constitutes an important empirical contribution to the literature on New Keynesian Phillips curves. In particular, their study is relevant for understanding one of the most fundamental macroeconomic phenomena: the relationship between real and nominal variables. It is also most useful for macroeconomic policy-makers, and especially for monetary authorities.

In this discussion, it has been shown that the conclusions reached by Kozicki and Tinsley are sensitive to the econometric method. More explicitly, tests focusing on autocorrelations and dynamic responses of inflation as well as cross-equation restrictions seem more powerful for discriminating among the various specifications. Also, the results are potentially sensitive to the selection of the inflation and output-gap measures, observation frequency, and sample period. Overall, this strongly suggests that sensitivity analyses are required.

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General Discussion*

Participants raised issues regarding the definition and measurement of the variable believed to drive inflation. Simon van Norden speculated that the use of the output gap, which is unobserved and subject to significant historical revisions, could be a cause of observed inflation persistence. Sharon Kozicki agreed that it could well be a contributing factor. Kozicki added, however, that she had started constructing a data set using CBO's¹ output gaps, which she maintains are subject to only small revisions. Similarly, Michael Dotsey asked whether Kozicki had examined the implications of using the more theoretically plausible marginal cost in place of the output gap as the key forcing variable for inflation. Kozicki responded that she had not, in part because her regression coefficients, estimated with the CBO's output gap data, were of the correct sign and statistically significant.

In response to Dotsey's second question, which focused on the differences in Canadian and U.S. results, Kozicki replied that they may be due to the fact that Canada was treated as a closed economy in the specification of the pricing equations, which is an incorrect assumption. Pierre Duguay later commented that the major difference between the United States and Canada is that Canada has a well-defined inflation target while the United States does not. Kozicki agreed that this has been true since the early 1990s, but her response was an explanation for the longer sample period differences in inflation persistence.

A number of questions were raised regarding the model of inflation expectations used. For example, Frank Smets noted that agents probably don't know the long-term inflation anchor, which is assumed by the model, and he suggested that this may account for the residual inflation persistence.

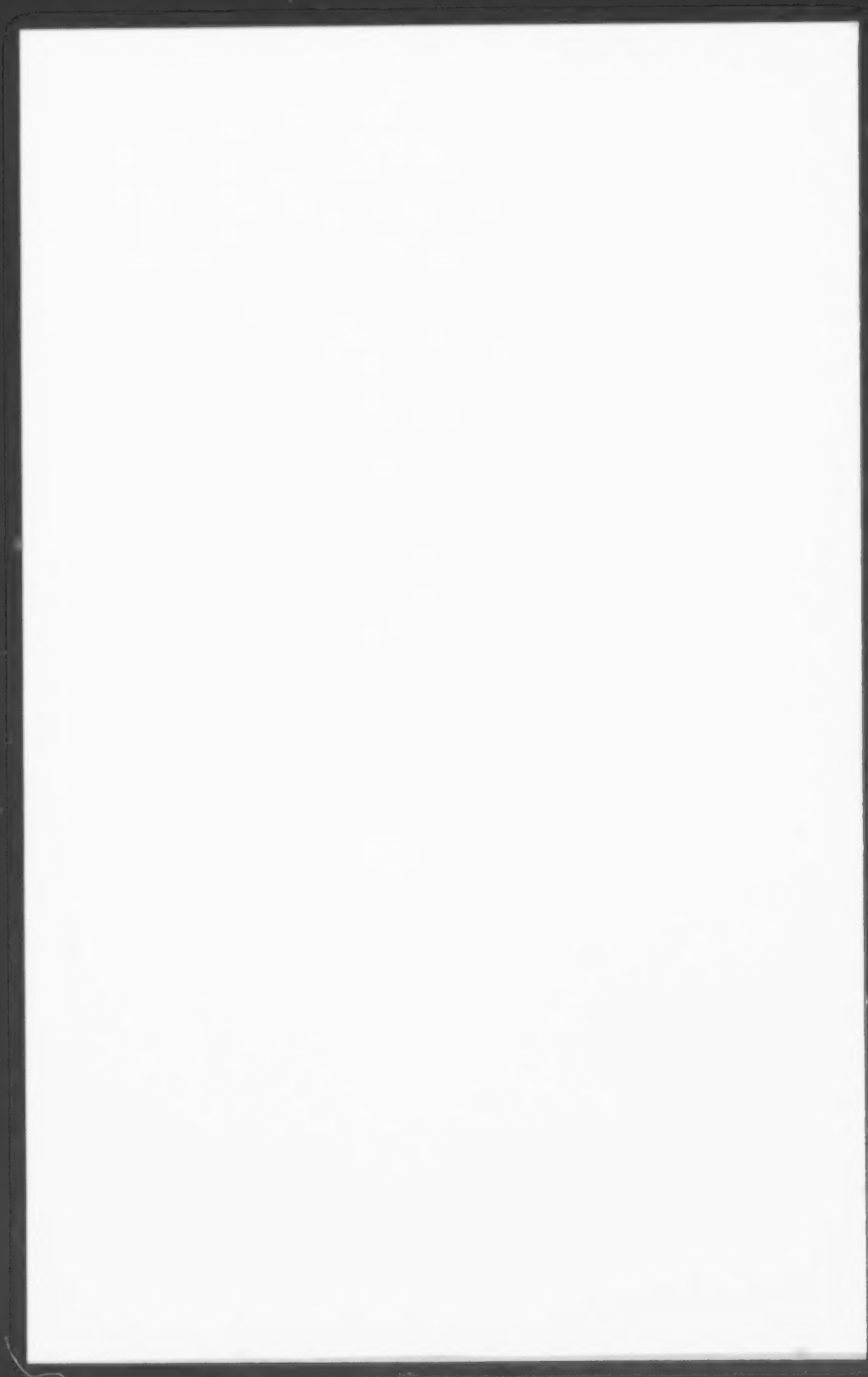
1. CBO: Congressional Budget Office.

* Prepared by Stephen Murchison and Nadja Kamhi.

Kozicki answered that she doesn't make this assumption, but she agreed that the model wasn't fully specified in that she was using the market perception of inflation as the long-term anchor. She stated that the two measures don't necessarily coincide, particularly when there is imperfect credibility. Kozicki expressed interest in developing a model that would account for this. Michael Woodford proposed a way of modifying the standard model to account for the changes in the perceived long-run inflation targets in the inflation equation. Drawing on the methodology used by Tack Yun, he explained that one can suppose that agents who are not re-optimizing their prices automatically increase their price at the perceived long-run inflation rate between the occasions when they re-optimize. By making the additional assumption that inflation is time-varying (in Yun's case, it is constant), one gets inflation deviations from perceived long-run inflation rates as well as deviations of recent past perceptions of the long-run inflation rate.

In the first of his two comments, Steven Ambler noted that using the wage equation with micro foundations will create a forward-looking model where wage inflation depends on expected future inflation and a marginal cost term for households. Second, he described a way to incorporate backward-looking terms into the Phillips equation. He said that by using a rich enough model of marginal cost in place of the output gap, one will obtain lagged capital cost, lagged employment, future expected capital cost, and future expected employment terms in the equation. Once these terms are quasi-differenced, there will be a lagged level of inflation in the Phillips curve equation.

Gregor Smith asked Kozicki whether she thought that inflation expectations or the output gap was the reason for the flat-line behaviour of inflation in the 1990s. She responded that this behaviour is explained by both factors and that additional terms may explain things a little more but are not as significant. Pierre Duguay's opinion was that the flat line is explained by inflation-targeting monetary policy.



The New Phillips Curve in Canada

Alain Guay, Richard Luger, and Zhenhua Zhu

Introduction

The short-run dynamics of inflation and the cyclical interaction of inflation with real aggregates are important issues both in theory and in practice, especially for central banks in their conduct of monetary policy. Recent high levels of economic activity coupled with low inflation, observed in several countries, cast doubt on the traditional Phillips curve as a model of inflation dynamics.

A recent class of dynamic stochastic general-equilibrium model integrates Keynesian features, such as imperfect competition and nominal rigidities, resulting in a new view of the nature of inflation dynamics. These models are grounded in an optimizing framework where imperfectly competitive firms are constrained by costly price adjustments. Within this framework, the process of inflation is described by the so-called New Keynesian Phillips curve (NKPC), which has two distinguishing features. First, the inflation process has a forward-looking component and second, it is related to real marginal costs. These features are a consequence of the fact that in this framework firms set prices in anticipation of future demand and factor costs. Compared with traditional reduced-form Phillips curves, which are subject to the Lucas critique, the NKPC is a structural model with parameters that are unlikely to vary as the policy regime changes. This aspect is important in a country such as Canada, because parameter instability in reduced-form models is a likely possibility since the adoption of an explicit inflation-targeting regime. Furthermore, the NKPC specification has dramatic implications for the conduct of monetary policy in that a fully credible central bank can bring about disinflation at no recessionary cost if inflation is a purely forward-looking phenomenon. A crucial issue is therefore whether the NKPC is empirically relevant.

The recent work of Galí and Gertler (1999) and Galí, Gertler, and López-Salido (2001a) provide evidence supporting the NKPC for the United States and the euro area. These authors estimate hybrid versions of the NKPC, where lags of inflation are also incorporated, and conclude that the forward-looking component is more important and, furthermore, that real marginal costs are statistically significant. In these studies, parameter estimates are obtained by the Generalized Method of Moments (GMM) and statistical significance is assessed based on Newey-West estimates of the covariance matrix.

In this paper, we examine the empirical relevance of the NKPC for Canada. We address several important econometric issues with the standard approaches typically used for estimation and inference in NKPC models. The main issues are related to the potential bias of GMM estimates in the presence of many instruments and the low power of specification tests based on overidentifying restrictions. The approach adopted in this paper attempts to mitigate these econometric problems. Furthermore, we investigate the robustness of our estimation results based on this improved approach relative to the choice of instruments.

The rest of the paper is organized as follows. In section 1, we present the theoretical framework that yields the NKPC, outline alternative measures of marginal cost, and show how open-economy considerations can be incorporated. In section 2, we describe the econometric issues associated with standard GMM estimation, discuss particular issues with estimation of the closed-form version of the NKPC, and present our estimation strategy based on the bias-corrected continuous updating estimator (CUE). In particular, using the same data set as Galí and Gertler (1999), we demonstrate the sensitivity of standard GMM estimates to the choice of instruments. In section 3, we describe various measures of the labour share with Canadian data and then, in section 4, we present the estimation results. A discussion of the main findings follows in section 5, and the final section concludes.

1 New Phillips Curves

The NKPC, as advocated by Galí and Gertler (1999), is based on a model of price-setting by monopolistically competitive firms. Adopting a price-setting rule as in Calvo (1983) simplifies the aggregation problem. This price-adjustment rule is in the spirit of Taylor's (1980) model of staggered contracts. Following Calvo, each firm, in any given period, may adjust its price with a fixed probability $1 - \theta$ and, with probability θ , its price will be

kept unchanged or proportional to trend inflation, Ω .¹ These adjustment probabilities are independent of the firm's price history, such that the proportion of firms that may adjust their price in each period is randomly selected. The average time over which a price is fixed is then given by $1/(1-\theta)$.

A firm that sets its price at the beginning of period t maximizes its stock market value by solving the following problem:

$$\max_{p_t^*(s)} E_t \sum_{i=0}^{\infty} (\theta\beta)^i \lambda_{t+i} [P_t^*(s)\Omega^i Y_{t+i}(s) - TC(Y_{t+i}(s))] \quad (1)$$

where $1-\theta$ is the probability that it may adjust its price at the beginning of a given period, β is the subjective discount rate of the representative owner of the firm, λ_{t+i} is the marginal utility of consumption of the representative owner in period $t+i$, and $Y_{t+i}(s)$ is the firm's output in period $t+i$. $TC(Y_{t+i}(s))$ is the firm's nominal total cost as a function of output. The firm faces a constant elasticity of demand for its output equal to μ . The solution of this maximization problem leads to optimal price-setting rules, which relate a firm's optimal price to its real marginal cost of production and to its expected future optimal price.

For a firm that adjusts its price at time t , the optimal reset price is given by:

$$p_t^* = (1-\beta\theta)E_t \sum_{j=0}^{\infty} (\beta\theta)^j mc_{t+j,t} \quad (2)$$

where $mc_{t+j,t}$ is the firm's nominal marginal cost (as a percentage deviation of the steady state) for a optimal price fixed at time t . This expression relates the optimal price to the stream of the future path of discounted nominal marginal cost of the individual firm. It can also be shown that the aggregate price, p_t , depends on the optimal reset price, p_t^* , and the lagged price level p_{t-1} through:

$$p_t = (1-\theta)p_t^* + \theta p_{t-1} \quad (3)$$

By combining equations (2) and (3), a Phillips curve relationship can be derived relating current inflation to expected future inflation and to firms' real marginal costs. To obtain a Phillips curve relationship of the average real marginal costs of a firm, the firm's real marginal cost has to be aggregated. Unfortunately, the aggregation problem has been solved only

1. This adjustment is necessary if there is trend inflation in order to preserve monetary neutrality in the aggregate.

under very restrictive assumptions. Yun (1996) and Goodfriend and King (1997) assumed that individual firms can instantaneously adjust their own capital stocks, so that the marginal productivity of capital is the same across all firms, and all firms have the same marginal cost. Danthine and Donaldson (2002) have criticized this approach, since it amounts to assuming that the costs of adjusting physical capital stocks are an order of magnitude smaller than the costs of adjusting prices. Shordone (2001) showed that under the assumption that firms' relative capital stocks do not vary with their relative prices, and (with a Cobb-Douglas production technology) firms' average marginal costs can be approximated by average unit labour costs. This assumption seems as unsatisfactory as Yun's, since if there is aggregate capital accumulation, then firms have identical rates of net investment. The approaches of both Yun and Shordone are theoretically unappealing and may be at odds with the data.

Ambler, Kurmann, and Guay (2002) show how to relate the average real marginal cost of firms that adjust their price to the average real marginal cost of firms without specific assumptions.

This New Phillips curve has the same functional form as previous New Phillips curves in the literature, but its parameters depend differently on the underlying structural parameters. In particular, the effects of average real marginal costs and future expected inflation on current inflation depend on both the elasticity of real marginal cost with respect to output and on the demand elasticities of firms.

By a first-order expansion:

$$mc_{t+j} \approx mc_{t+j,t} + \frac{\partial mc_{t+j,t}}{\partial y_{t+j,t}} \frac{\partial y_{t+j,t}}{\partial p_t^e} (p_{t+j} - p_t^e),$$

where $mc_{t+j,t}$ is the real marginal cost of the firm at $t+j$ when its price is fixed at t , and $y_{t+j,t}$ is the firm's output at $t+j$ for a price fixed at t . We can rewrite this as:

$$mc_{t+j,t} \approx mc_{t+j} - \eta \mu (p_t^e - p_{t+j}), \quad (4)$$

where η is the elasticity of marginal cost with respect to output, and μ represents the demand elasticities of firms.

The New Phillips curve is then given by:

$$\pi_t = \frac{(1-\theta)(1-\theta\beta)}{\theta-\theta\eta\mu} mc_t + \beta E_t \pi_{t+1}. \quad (5)$$

The derivations in Yun (1996) and Goodfriend and King (1997) correspond to the case where the elasticity of marginal cost with respect to output (η) is equal to zero. Indeed, the hypothesis that individual firms can instantaneously adjust their own capital stocks implies that firms act as price-takers in the input market. Combined with a constant return to scale technology, real marginal cost is then independent of output.

Under the assumption that the relative capital stock does not vary with changes in the relative price or relative output, the individual firm's real marginal cost is related to the aggregate real marginal cost by the following expression:

$$mc_{i,t} = mc_t + \frac{\alpha}{(1-\alpha)} \mu (p_t^* - p_t),$$

which can be rewritten as

$$mc_{i,t} = mc_t + \frac{\alpha}{(1-\alpha)(1-\theta)} \mu \pi_t,$$

where α is the capital share in the constant return to scale Cobb-Douglas production. With the general formulation (4), this assumption implies the following relationship:

$$\frac{\alpha}{(1-\alpha)} = \eta,$$

which was also shown to hold by Ambler, Kurmann, and Guay (2002).

Finally, under certain conditions, average marginal costs are in turn related to output, thereby linking the New Phillips curve with the traditional Phillips curve (which has the output gap as a key explanatory variable).

Gali and Gertler (1999) extend the basic Calvo model to allow a subset of firms to use a backward-looking rule of thumb to capture the inertia in inflation. The hybrid version of the Phillips curve for the general formulation developed by Ambler, Kurmann, and Guay (2002) is given by:

$$\pi_t = \lambda \left(\frac{1}{(1-\eta\mu)} \right) mc_t + \gamma_f E_t \pi_{t+1} + \gamma_b \pi_{t-1},$$

where

$$\lambda = \left(\frac{(1-\omega)(1-\theta)(1-\theta\beta)}{\theta} \right) \phi^{-1},$$

$$\gamma_f = \beta\theta\phi^{-1},$$

$$\gamma_b = \omega\phi^{-1},$$

$$\phi = \theta + \omega[1 - \theta(1 - \beta)],$$

and where ω is the proportion of firms that use a backward-looking rule of thumb. The corresponding hybrid New Phillips curve for the aggregate assumption considered by Yun (1996) and Goodfriend and King (1997) is derived in Galí and Gertler (1999) and the one based on the assumption of Sbordone (2001) in Galí, Gertler, and López-Salido (2001). One can easily retrieve these specific forms from the general form given above.

1.1 Measures of marginal cost

Alternative measures of the marginal cost have been considered in empirical investigations of the NKPC. The simplest measure of real marginal cost is based on the assumption of Cobb-Douglas technology (see Galí and Gertler 1999). Suppose the following Cobb-Douglas production function:

$$Y_t = K_t^\alpha (A_t H_t)^{(1-\alpha)},$$

where K_t is the capital stock, A_t is labour-augmenting technology, and H_t represents hours worked. Real marginal cost is then given by $S_t/(1-\alpha)$, where $S_t = W_t H_t / P_t Y_t$ is the labour-income share. In log-linear deviation from the steady state, we have:

$$mc_t = s_t = w_t + h_t - p_t - y_t.$$

Rotemberg and Woodford (1999), Galí, Gertler, and López-Salido (2001a), Gagnon and Khan (2001), and Sbordone (2001) consider a Cobb-Douglas technology with overhead labour cost. In this case, the production function has the following form:

$$Y_t = K_t^\alpha (A_t (H_t - \bar{H}))^{(1-\alpha)},$$

where the term $\bar{H}$ is the hours that need to be worked irrespective of the level of production. Expressed in log-linear deviations, we have from Sbordone (2001) that

$$mc_t = s_t + b h_t,$$

where

$$b = \frac{\bar{H}/H}{1 - \bar{H}/H}$$

and H is the number of hours worked at the steady state. The measure of marginal cost is in this case augmented by a term that depends on hours worked.

Finally, we can consider adjustment costs of labour. To this end, we specify the following functional form for the adjustment cost of labour:²

$$\frac{\phi}{2}(H_t - H_{t-1})^2,$$

where ϕ is the coefficient controlling the adjustment labour cost. It can be shown that real marginal cost in log-linear deviations is then given by:

$$mc_t = s_t + \phi H \left(\frac{H}{(1-\alpha)Y} \right) \Delta H_t - \beta \phi H \left(\frac{H}{(1-\alpha)Y} \right) E_t \Delta H_{t+1}, \quad (6)$$

where H/Y is the steady-state value of the hours worked share in output. This specification of the real marginal cost implies more dynamics by the intermediary of the expectation of hours worked than the previously considered specifications.

1.2 Open-economy considerations

Following Galí and Monacelli (2002), in the case of an open economy, the real marginal cost can be expressed in log-linear deviations as:

$$mc_t = s_t + (\tilde{p}_t - p_t),$$

where $\tilde{p}_t$ corresponds to the consumer price index.³ The variable $\tilde{p}_t$ is defined by the following expression:

$$\tilde{p}_t = (1 - \Theta)p_t + \Theta p_{mt},$$

where p_{mt} is the import price index (in log deviation), and Θ measures the degree to which the economy is open. By combining these two expressions, the real marginal cost can be rewritten as:

2. Ambler, Guay, and Phaneuf (1999) present estimates of the parameter associated with the adjustment cost of labour in a dynamic stochastic general-equilibrium model.

3. See also Ambler, Kurmann, and Guay (2002) for an alternative derivation of this expression for the real marginal cost.

$$mc_t = s_t + \Theta(p_{mt} - p_t), \quad (7)$$

where $(p_{mt} - p_t)$ corresponds to the terms of trade.

By the law of one price, the real exchange rate is proportional to the terms of trade (Galí and Monacelli 2002). Therefore,

$$q_t = (1 - \Theta)(p_{mt} - p_t),$$

where q_t is the real exchange rate. The real marginal cost can then be expressed as a function of the real exchange rate, as follows:

$$mc_t = s_t + \frac{\Theta}{1 - \Theta} q_t. \quad (8)$$

The estimation of the NKPC in the open-economy case will be based on specifications (7) and (8).

2 Estimation Issues

2.1 Standard GMM approach

The hybrid model in reduced form can be written as:

$$\pi_t = \gamma_f \pi_{t+1} + \gamma_b \pi_{t-1} + \lambda mc_t + \varepsilon_{t+1}, \quad (9)$$

where ε_{t+1} is an expectational error term orthogonal to the information set in period t , i.e.,

$$E[(\pi_t - \gamma_f \pi_{t+1} - \gamma_b \pi_{t-1} - \lambda mc_t) Z_t] = 0, \quad (10)$$

where Z_t is a vector of instruments dated t and earlier. The orthogonality condition in equation (10) then forms the basis for estimating the model by the GMM. Galí and Gertler (1999) use this technique with four lags each of inflation, the labour income share, the output gap,⁴ the long-short interest rate spread, wage inflation, and commodity price inflation. Finally, they use a 12-lag Newey-West estimate of the covariance matrix to obtain standard errors for the model parameters. Based on these choices, they conclude that: (i) the model is statistically significant; and (ii) γ_f is statistically larger than γ_b . They interpret these results as support for the NKPC in the case of the United States. Given the relatively large number of moment conditions,⁵ the

4. Typically, the output gap is obtained by application of the Hodrick-Prescott filter or by fitting a quadratic trend to the entire sample. Using such measures of the output gap as instruments is invalid since they violate the basic GMM orthogonality condition.

5. In fact, 24 moment conditions to estimate three reduced-form parameters.

estimates reported by Gali and Gertler are potentially biased, since it is well known that the estimation bias increases with the number of moment conditions in the standard GMM approach (Newey and Smith 2001). To illustrate this effect, consider the following Monte Carlo experiment. Suppose the data are generated by the ARMA process:

$$y_t = \rho y_{t-1} + \varepsilon_t + \theta \varepsilon_{t-1},$$

where $\rho = 0.1$, $\theta = 0.5$, and $\varepsilon_t \sim i.i.d. N(0, 1)$. Consistent estimates of ρ are obtained by GMM. The moment conditions are based on

$$E(\varepsilon_t Z_t) = 0,$$

where $Z_t = (y_{t-2}, y_{t-3}, \dots, y_{t-k})'$ is a vector of valid instruments (since it excludes y_{t-1}). The sample size is fixed at 100, and we study the effect of an increase in the number of moment conditions. The Monte Carlo experiment is based on 10,000 replications, and the automatic lag selection procedure of Newey and West (1994) is used to obtain an estimate of the weighting matrix. Table 1 reports the bias of the GMM estimator as a function of the number of moment conditions, $k - 2$. The bias of the GMM estimator clearly increases with the number of moments (lags of y_t) included in the vector of instruments. With two instruments, the estimator is nearly unbiased. With ten instruments, the bias appears to be of the same order as the true parameter value. This simple Monte Carlo experiment concurs with the theoretical results of Newey and Smith (2001).

Table 1
Bias of GMM estimator

$k - 2$	ρ_{GMM}	bias
2	0.0942	-0.0058
3	0.1157	0.0157
4	0.1209	0.0109
5	0.1410	0.0410
6	0.1446	0.0446
7	0.1607	0.0607
8	0.1716	0.0716
9	0.1799	0.0799
10	0.1932	0.0932

A number of studies have also estimated NKPCs in countries other than the United States, applying equally arbitrary choices for the instrument set and

the number of lags used in the construction of Newey-West standard errors.⁶ See, for example, Batini, Jackson, and Nickell (2002); Galí, Gertler, and López-Salido (2001a); Gagnon and Khan (2001); and Balakrishnan and López-Salido (2002).

To appreciate the relative importance of these choices within a standard GMM context, let $\gamma = \gamma_f$ and consider the reduced form under the constraint $\gamma_f + \gamma_b = 1$:

$$\pi_t(\gamma) = \lambda(\gamma)mc_t + \varepsilon_{t+1}, \quad (11)$$

where $\pi_t(\gamma) = \pi_t - \pi_{t-1} - \gamma(\pi_{t+1} - \pi_{t-1})$. For a fixed value of $\gamma \in [0, 1]$, the parameter $\lambda(\gamma)$ can be consistently estimated by instrumental variables, using lagged values of real marginal cost dated t and earlier.

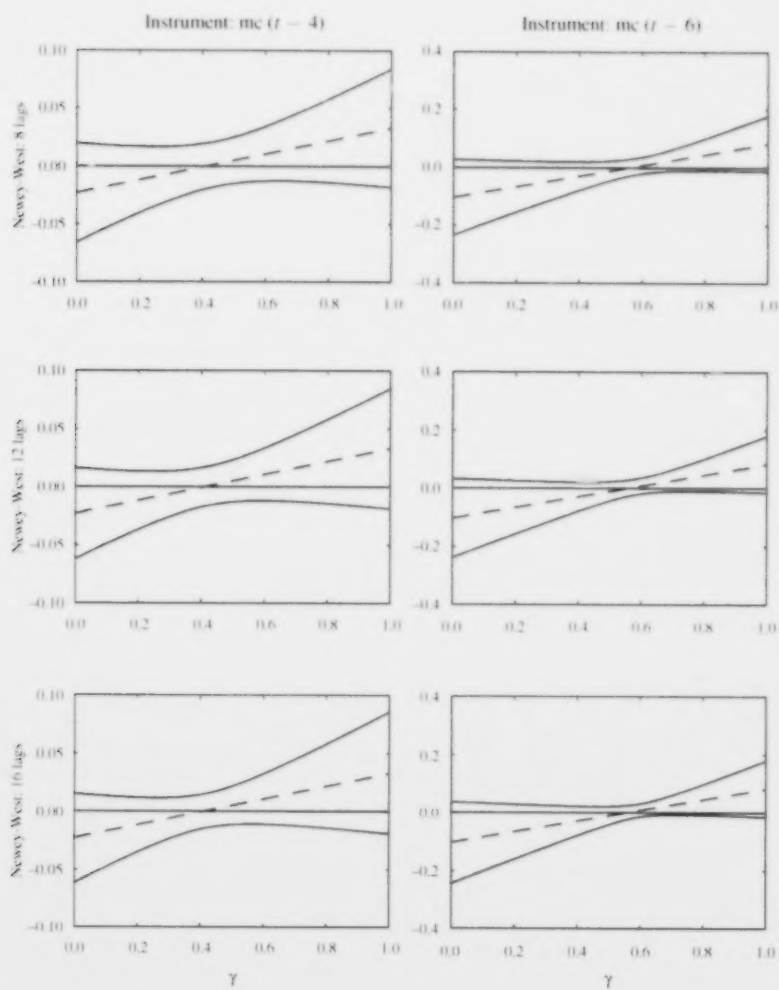
Using the same data set⁷ as Galí and Gertler (1999), Figure 1 shows the effects of different instruments and those of various lags in constructing Newey-West estimates of the standard deviation. For a given instrument, it appears that there is little effect whether 8, 12, or 16 lags are used for the Newey-West standard errors. On the other hand, it is clear that the choice of instrument is crucial, especially at the upper end of the interval $[0, 1]$, where the forward-looking component in the New Phillips curve is more important. When the sixth lag of marginal cost is used as the instrument, marginal costs tend to appear marginally significant for some values of the forward-looking component parameter near 0.7, while it is clearly insignificant when the fourth lag is used as the instrument. Note also the increased precision when the fourth lag is used as the instrument as reflected by the relatively tighter confidence bands. The difference in the width of the confidence bands is expected, since the more recent lags are more strongly correlated with contemporaneous marginal cost and hence are better instruments.

Overall, these results cast doubt on the robustness of the results reported by Galí and Gertler (1999) and on the significance of marginal costs in explaining U.S. inflation.

6. A few notable exceptions are Jondeau and Le Bihan (2001) and Lindé (2001) who consider full information maximum likelihood approaches.

7. The data are quarterly for the United States over the period 1960Q1–1997Q4. Inflation is the annualized change in the logarithm of the GDP deflator, and real marginal costs are measured as deviations from the sample mean of the logarithm of labour income share in the non-farm business sector.

Figure 1
Effects of different instrumental variables



Notes: The dashed line in each graph shows the instrumental variable (IV) estimates of $\lambda(\gamma)$ in the model $\pi_t(\gamma) = \lambda(\gamma)mc_t + \varepsilon_{t+1}$, where the instrument used is either the fourth lag (left panel) or the sixth lag (right panel) of real marginal cost. Newey-West standard errors are used to construct the 95 per cent confidence bands, using either 8, 12, or 16 lags.

2.2 Closed-form estimation à la Rudd-Whelan

As shown in Galí and Gertler (1999), the hybrid Phillips curve has the following closed form, conditional on the expected path of real marginal cost:

$$\pi_t = \delta_1 \pi_{t-1} + \frac{\lambda}{\delta_2 \gamma_f} \sum_{k=0}^{\infty} \delta_2^{-k} E_t[mc_{t+k}], \quad (12)$$

where δ_1 and δ_2 are, respectively, the stable and unstable roots of the hybrid Phillips curve given by:

$$\delta_1 = \frac{1 - \sqrt{1 - 4\gamma_b \gamma_f}}{2\gamma_f}, \quad \delta_2 = \frac{1 + \sqrt{1 - 4\gamma_b \gamma_f}}{2\gamma_f}. \quad (13)$$

An alternative to the standard GMM approach is to directly estimate the closed-form representation, as done in Rudd and Whelan (2001) and Galí, Gertler, and López-Salido (2001a). Under rational expectations, the closed form defines the following orthogonality conditions:

$$E_t \left[\left(\pi_t - \delta_1 \pi_{t-1} - \frac{\lambda}{\delta_2 \gamma_f} \sum_{k=0}^{\infty} \delta_2^{-k} mc_{t+k} \right) Z_t \right] = 0, \quad (14)$$

where Z_t is a vector of instrumental variables.

With this approach, it is necessary to use a truncated sum to approximate the infinite discounted sum of real marginal costs. Based on an assumed value for the discount factor β , Rudd and Whelan use 12 leads of real marginal cost to construct the discounted stream of real marginal costs. Galí, Gertler, and López-Salido, on the other hand, use 16 leads and differ by estimating the discount factor instead of fixing its value arbitrarily. In both cases, however, there is loss of degrees of freedom because of the need to truncate the sum, which can be important given the relatively small sample size (typically about 30 years of quarterly data). Furthermore, given the way the measure of the discounted stream of future marginal cost is constructed, there is a generated regressor problem. To see this, consider the limiting case of pure forward-looking behaviour. In that case, the closed form, under rational expectations, becomes

$$\pi_t = \lambda \sum_{k=0}^{\infty} \beta^k mc_{t+k} + u_{t+1}, \quad (15)$$

where the new error term, u_{t+1} , is related to the original expectational error term, ε_{t+1} , by

$$u_{t+1} = \varepsilon_{t+1} + \gamma_f \pi_{t+1} - \lambda \sum_{k=1}^{\infty} \beta^k m c_{t+k}, \quad (16)$$

and from which the generated regressor problem is apparent. Since u_{t+1} in equation (16) is serially correlated (into to the indefinite future), it is essential that the efficiency of the GMM estimator and the consistency of the associated standard errors be evaluated. Clearly, this problem is also present in the hybrid Phillips curve. Estimation in the presence of generated regressors leads, in general, to inefficient estimates that require adjustments to obtain consistent estimates of their standard errors (see Pagan 1984, 1986; Murphy and Topel 1985; and McAleer and McKenzie 1991a, b). Galí, Gertler, and López-Salido (2001b) recognize this problem, but no attempt is made to evaluate it.

Another problem associated with the closed form is that it involves locally almost unidentified (LAU) parameters such that use of Wald-type confidence intervals is invalid. The problem here is that the ratio $\lambda/(\delta_2 \gamma_f)$ has a discontinuity at every point of the parameter space where $\gamma_f = 0$. From Dufour (1997), it is then known that one can find a value of this ratio such that the distribution of the Wald statistic will deviate arbitrarily from any "approximating distribution" (such as the standard normal distribution). This suggests that Wald-type inference on structural parameters that appear in NKPC models in ratio form is, in general, an issue for any of the usual estimation approaches. Other techniques, such as confidence sets based on the inversion of likelihood ratio tests, would yield valid inference on the LAU structural parameters. Note that Wald-type inference remains valid for the "non-LAU" reduced-form parameters.

2.3 Estimation strategy

Our estimation strategy differs in three important ways from other empirical studies of the NKPC. First, we use bias-corrected estimators as proposed by Newey and Smith (2001). Second, an automatic lag-selection procedure proposed by Newey and West (1994) is adopted to compute estimates of the variance-covariance matrix of the moment conditions.

As shown by several studies, the small sample properties of method-of-moments estimators depends crucially on the number of lags used in the computation of this variance-covariance matrix. Moreover, our estimator of the variance-covariance matrix uses the sample moments in mean deviation in order to increase the power of the overidentifying restrictions test as

suggested by Hall (2000). A more powerful specification test is clearly desirable, since it addresses the issues raised by Dotsey (2002) who found that the conventional specification test used in Gali and Gertler (1999) lacks power. Third, an alternative estimator is used for the non-linear specification. This estimator has the advantage that it does not depend on the normalization of the moment conditions, in contrast to the conventional GMM estimator.

We begin by presenting an alternative estimator to the conventional two-step GMM estimator: the CUE, introduced by Hansen, Heaton, and Yaron (1996). We then present bias-corrected linear IV, GMM, and CUE, as proposed by Newey and Smith (2001).

The optimal two-step GMM estimator of Hansen (1982) based on the moment condition

$$E[g(z_t, \beta_0)] = 0$$

is defined as

$$\hat{\beta} = \arg \min_{\beta \in B} \frac{1}{T} \sum_{t=1}^T g(z_t, \beta)' \hat{\Omega}(\tilde{\beta})^{-1} \frac{1}{T} \sum_{t=1}^T g(z_t, \beta),$$

where $\tilde{\beta}$ is a first-step estimator usually obtained with the identity matrix as weighting matrix, and where $\hat{\Omega}^{-1}$ is a consistent estimator of the inverse of the variance-covariance matrix of the moments conditions.

The CUE is analogous to GMM, except that the objective function is simultaneously minimized over β and $\hat{\Omega}(\beta)$. This estimator is given by

$$\hat{\beta} = \arg \min_{\beta \in B} \frac{1}{T} \sum_{t=1}^T g(z_t, \beta)' \hat{\Omega}(\beta)^{-1} \frac{1}{T} \sum_{t=1}^T g(z_t, \beta).$$

This estimator has important advantages compared with the conventional two-step estimator. First, unlike GMM, the estimator does not depend on the normalization of the moment conditions. As shown by Gali and Gertler (1999), the results obtained for the New Phillips curve and the hybrid version depend on the normalization adopted for the GMM estimation procedure. Second, Newey and Smith (2001) have shown that the asymptotic bias of CUE does not increase with the number of moment conditions. Hansen, Heaton, and Yaron (1996) show that in small samples, the CUE has smaller bias for IV estimators of asset-pricing models with several overidentifying restrictions compared with that of GMM.

Several approaches exist to correct for biases, including the jackknife, the bootstrap, subsampling, and analytical methods. Newey and Smith (2001) proposed an analytical bias correction for GMM and CUE estimators based on asymptotic bias formulas. Those formulas are derived from a stochastic expansion to study higher than $1/\sqrt{T}$ order properties of GMM and Generalized Empirical Likelihood estimators. The bias-corrected CUE is used for estimation of the non-linear specification. The bias formulas from Newey and Smith (2001) are adapted to a dynamic context.⁸ This analytical bias correction is much simpler computationally than resampling methods, especially in non-linear models.

3 Measuring the Labour Share with Canadian Data

The labour share is given by:

$$\text{labour share} = \frac{WN}{PY}, \quad (17)$$

where WN is nominal labour income and PY is nominal output. From this basic definition, several measures of labour share can be constructed using available Canadian data.

A natural measure of the labour share is simply the ratio of total compensation of employees in the economy divided by the national income, i.e.,

$$\text{lshare} = \text{wages and salaries} / \text{total GDP}.$$

There are, however, some conceptual issues with the appropriate measure to use in order to be consistent with the model's theoretical framework. First, the measure should be net of indirect taxes, since these accrue to the government and do not constitute compensation to employees. A measure of labour share adjusted for the effects of taxes is then constructed as equation (17), but now the denominator is total GDP less indirect taxes less subsidies on factors of production and on products.

Next, an adjustment should be made to account for the remuneration of the self-employed. Given available data, the income of non-farm unincorporated businesses can be added to the numerator of equation (17) in order to account for that part of the remuneration of the self-employed that constitutes a return to labour rather than to capital. These two effects can be accounted for jointly, yielding a measure of labour share adjusted for taxes and self-employment.

8. Detailed derivations of the formulas are presented in Guay and Luger (2002).

The first three measures of labour share just described are constructed using income-based GDP from the National Income and Expenditure Accounts, which is measured at market prices. Alternatively, measures based on factor costs can be considered in determining the labour share. These can be constructed by using the wages and salaries disaggregated by industry, and the GDP at factor cost also at the industry level. By using industry-level data, sectors where the theory does not apply can be excluded from the measures of the labour share. For example, the public sector can be excluded, since the concepts of labour and capital shares arguably apply only to the market sector of the economy. The farm sector can also be excluded because of the very large subsidies that farmers receive. This preferred measure is then constructed as

$$\text{lshare}_{\text{ntb}} = (\text{all industries, wages and salaries} - \text{farm wages and salaries} - \text{public wages and salaries}) / (\text{all industries GDP} - \text{farm GDP} - \text{public GDP}).$$

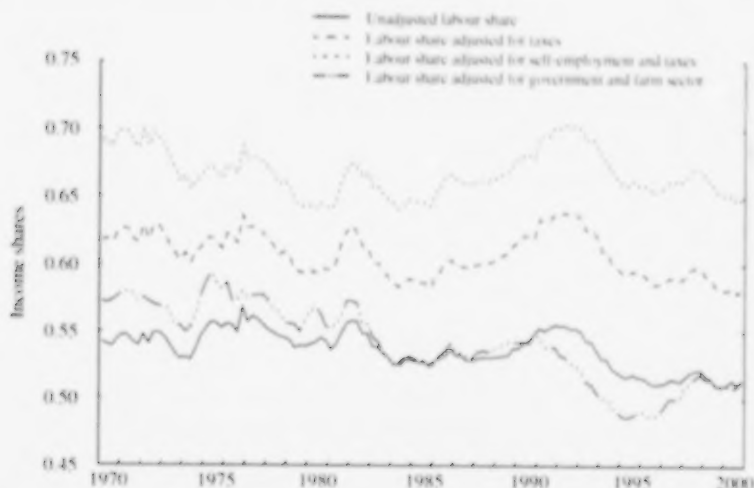
The levels of the different measures of the labour share are shown in Figure 2, where they seem to move in a similar fashion over the sample period. Figures 3 and 4 show each measure in percentage deviation from its mean, together with the inflation series (based on the GDP deflator).

It becomes clear from these figures that the various measures of the labour share have very different relationships to inflation. Dynamic cross-correlations are presented in Figures 5 and 6, where it is obvious that the fourth measure described above is potentially the most promising as the explanatory variable for Canadian inflation.

Note how the third measure co-moves negatively with most leads and lags of inflation. Figure 7 shows the dynamic cross-correlations between inflation and taxes less subsidies on factors of production and on products (top panel), and between inflation and income of non-farm unincorporated businesses (bottom panel).

The strong negative co-movements seen in these figures explain why the third measure adjusted for taxes and self-employment is inconsistent with the new Phillips curve. One possible explanation for the negative co-movement between taxes (less subsidies) and leads and lags of inflation is that the period of high oil prices in the 1970s and early 1980s was also accompanied by high subsidies on imported oil. On the other hand, the negative co-movements between income of the self-employed and leads and lags of inflation might simply be due to the substantial upward trend in self-employment vis-à-vis the downward movements in inflation. Finally, the autocorrelation functions of the different measures of the labour share are

Figure 2
Alternative measures of the labour share



presented in Figures 8 and 9. The fourth measure displays the strongest persistence, a well-known feature of the inflation process.

4 Results for Canada

4.1 Baseline model estimates

We first present estimates for the reduced form of the NKPC equation (5) given by:

$$\pi_t = \kappa \lambda m c_t + \beta E_t \pi_{t+1},$$

where $\kappa = 1/(1 - \eta\mu)$. If one follows Yun (1996) and Goodfriend and King (1997), then $\kappa = 1$, whereas following Shordone (2001), $\kappa = \frac{\alpha}{(1 - \alpha)\mu}$.

This reduced-form specification is estimated over the sample period 1970Q1–2000Q4. As mentioned, inflation is based on the GDP deflator, and $m c_t$ is the real marginal cost in log-deviation from its mean, calculated as the labour share of non-farm business. Several sets of instruments are used to investigate the robustness of the estimation results. They are: [1] two lags of inflation and real marginal cost, [2] three lags of inflation and real marginal cost, [3] four lags of inflation and real marginal cost, and [4] four

Figure 3
Inflation and different measures of the labour share

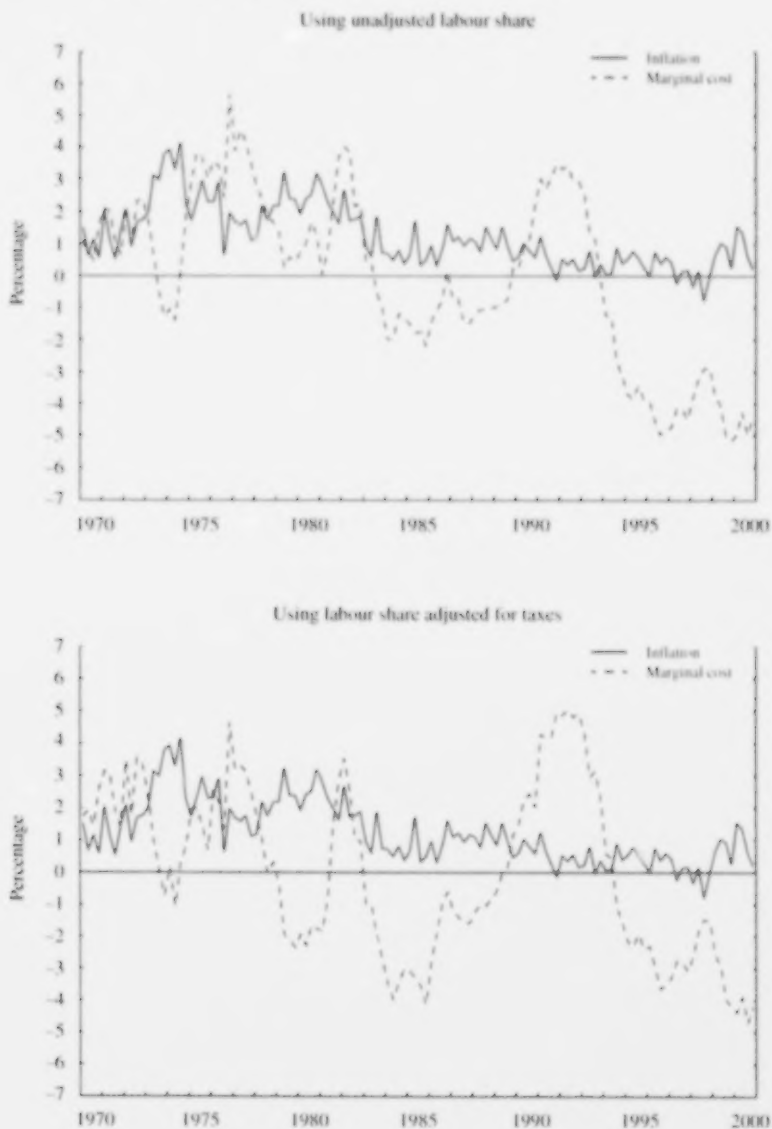


Figure 4
Inflation and different measures of the labour share

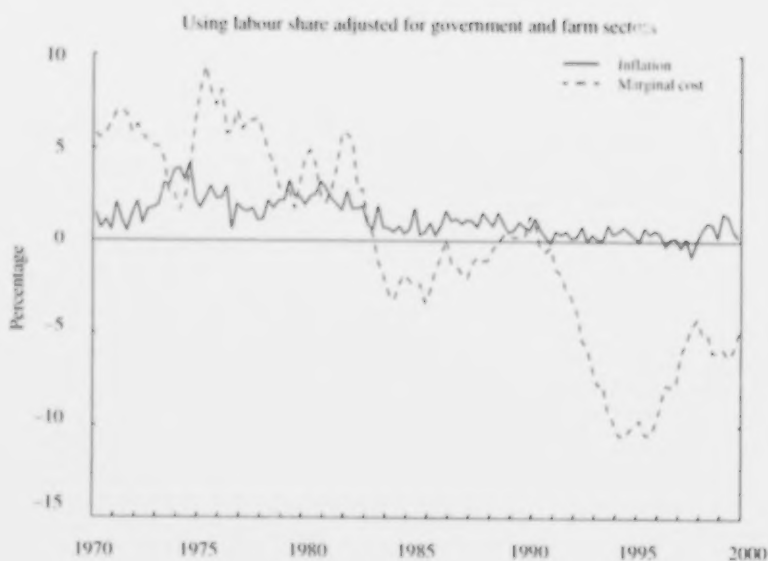
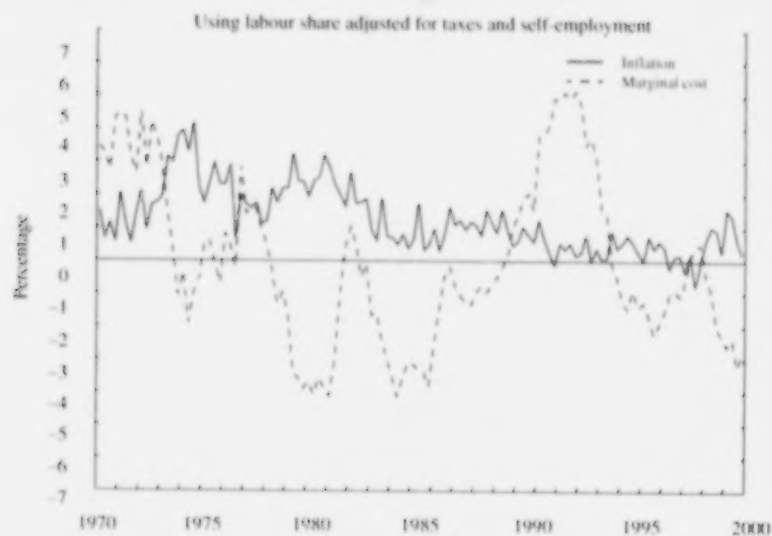


Figure 5
Dynamic cross-correlations: 1970 to 2000

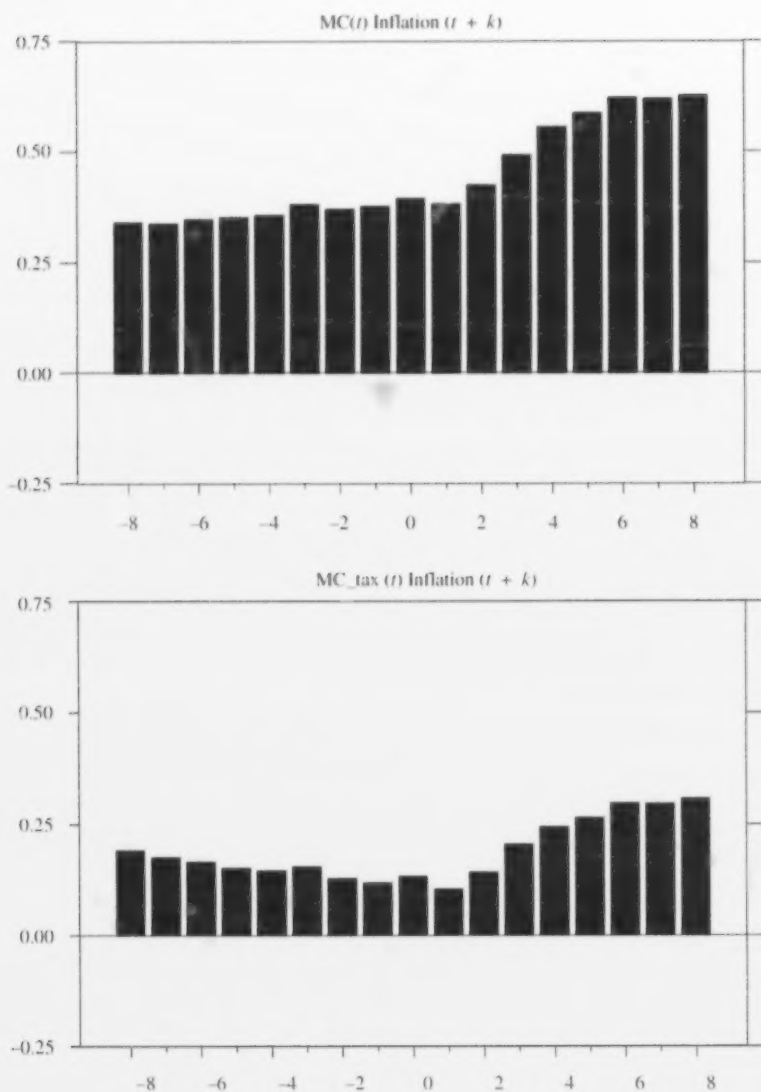


Figure 6
Dynamic cross-correlations: 1970 to 2000

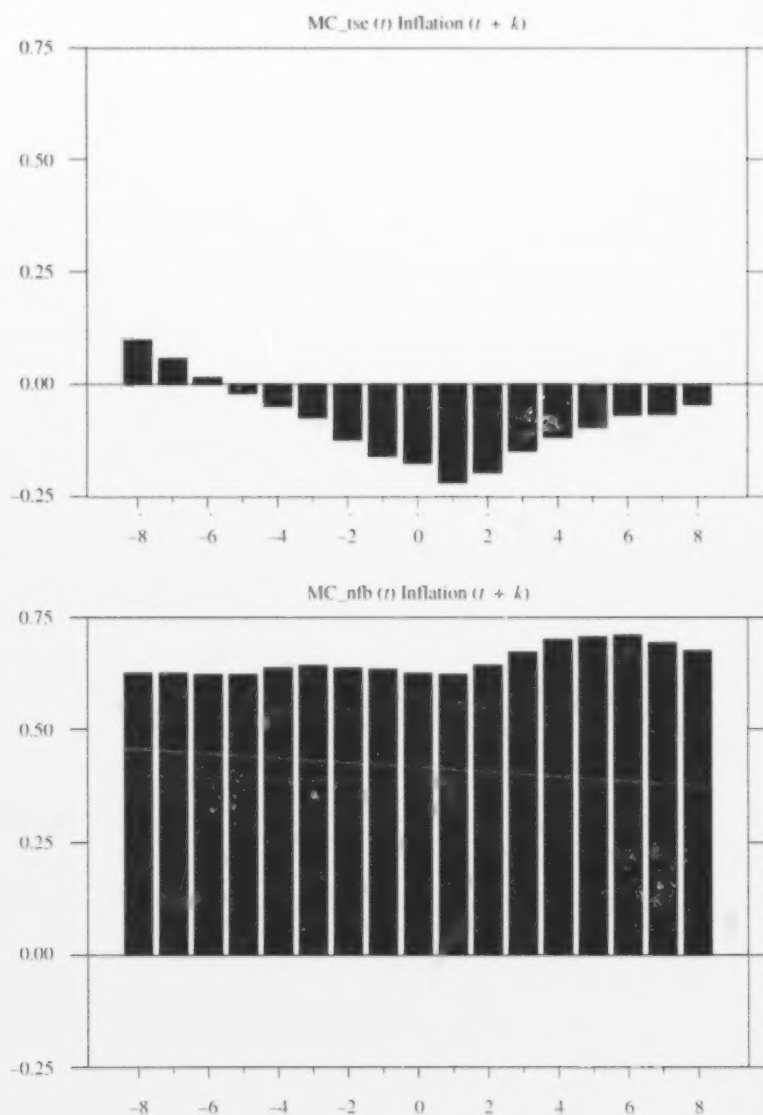


Figure 7
Dynamic cross-correlations: 1970 to 2000

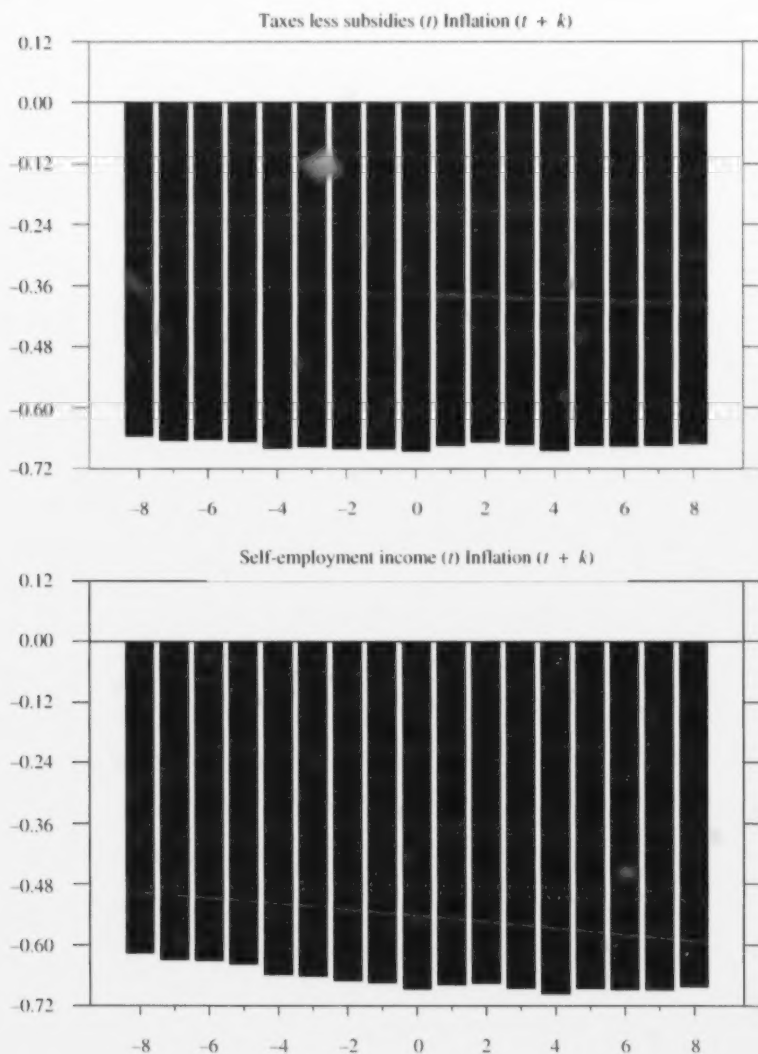


Figure 8
Autocorrelation function

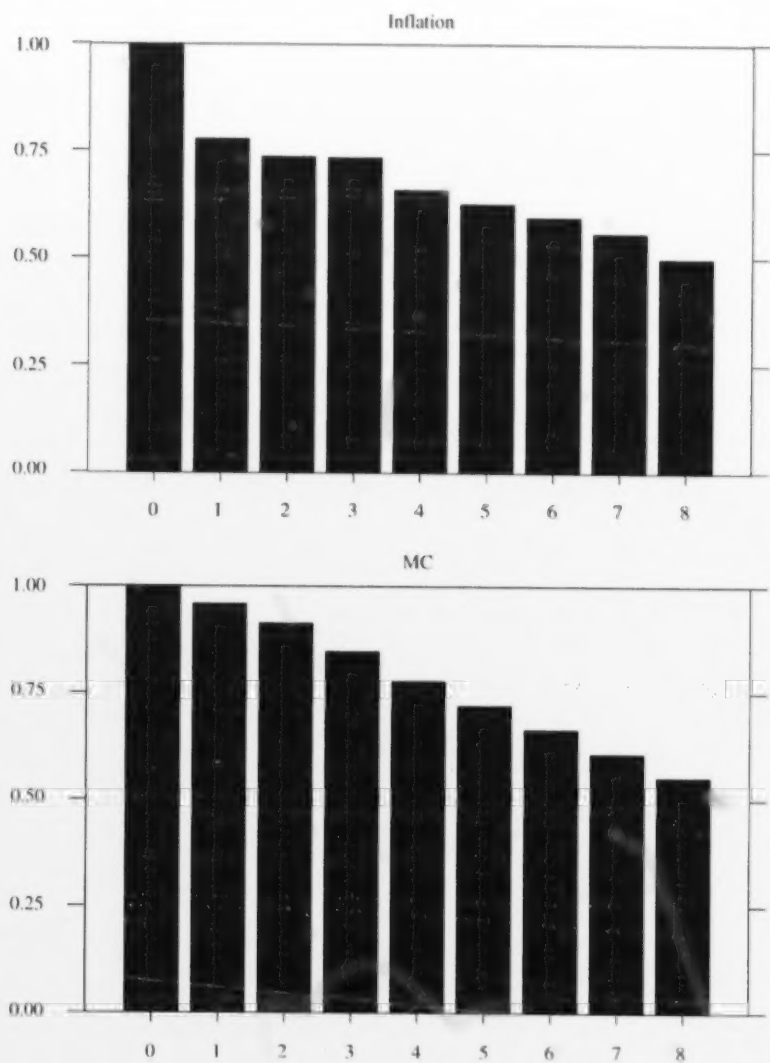
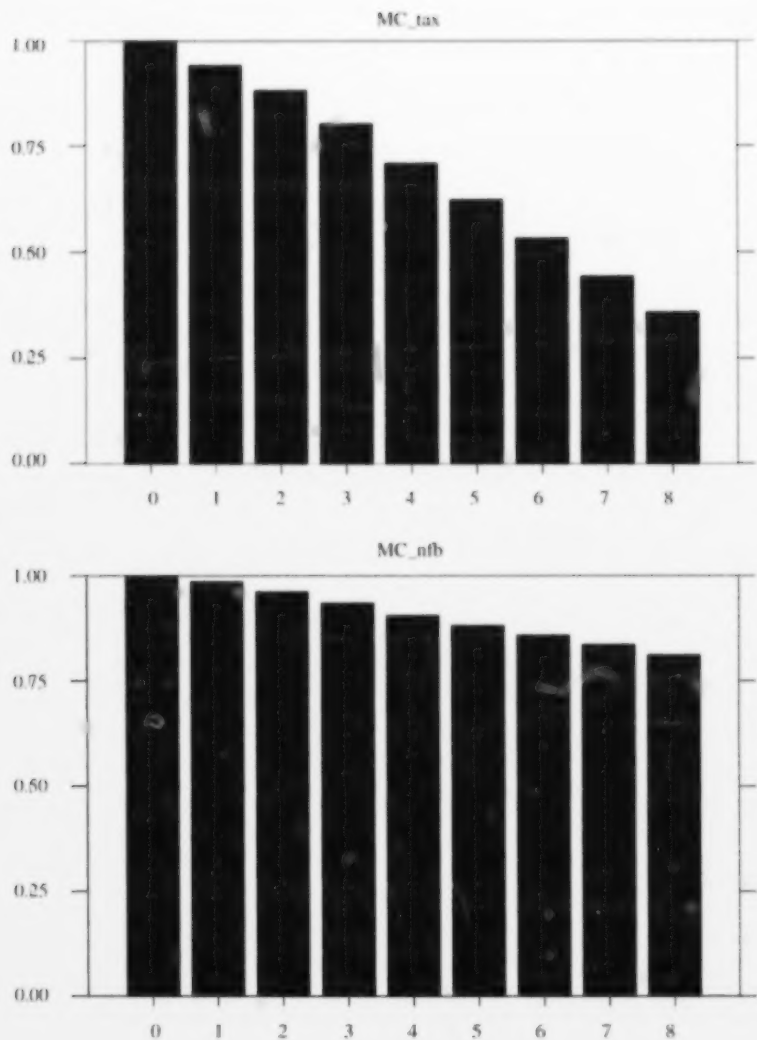


Figure 9
Autocorrelation function



lags of inflation, real marginal cost, and nominal wages. Instruments dated $t - 1$ and earlier are used to mitigate possible correlations with the measurement error of real marginal cost.

We depart from earlier studies by excluding output-gap measures from the instrument sets. Two measures of output gap are usually retained as instruments. One is based on quadratically detrended output. With standard unit-root tests (such as the Augmented Dickey-Fuller), the presence of a unit root in Canadian output cannot be rejected. Under the maintained hypothesis of a unit root, quadratically detrended output is then also characterized by a unit root. Unfortunately, the asymptotic properties of IV estimators in the presence of non-stationary instruments are not known. As a result, usual inference procedures are likely to be invalid. The other measure of output gap usually used is based on the Hodrick-Prescott filter. The output gap is then a combination of lags, leads, and contemporaneous values of output. Such measures of the output gap violate the basic GMM orthogonality conditions and are likely to be correlated with the measurement error of real marginal cost.

The GMM estimator for this linear specification corresponds to the IV estimator (two-stage least squares), which we correct for bias, as explained above. We also use a heteroscedasticity and autocorrelation-consistent matrix estimator for the sample moments in deviations from the mean to increase the power of the overidentifying restrictions test, as suggested by Hall (2000) and Bonnal and Renault (2001). The automatic lags selection procedure proposed by Newey and West (1994) is adopted. Table 2 reports the results for $\kappa = 0.13$. This value is proposed by Gagnon and Khan (2001) for Canada following the assumptions in Shordone (2001). It is important to understand that the inference results based on the reduced form do not depend on κ . While the scaling of the parameter λ depends on κ , its statistical significance does not, since the value of κ is a fixed constant that cancels out from the t -statistic.

The results are not encouraging for the NKPC. The slope coefficient on marginal cost is never significant whatever the set of instruments. For three cases, the coefficient has the wrong sign, and the discount factor is greater than one in all cases. Finally, the overidentifying restrictions are rejected with the instrument sets, which include four lags of inflation and real marginal cost. It appears that the New Phillips curve is misspecified, and richer dynamics would seem necessary to capture the persistence of Canadian inflation.

Table 2
Reduced-form estimates

Instrument set	β	λ	<i>J</i> -stat.
[1]	1.017 (0.000)	-0.0024 (0.947)	2.83 (0.419)
[2]	1.010 (0.000)	-0.0084 (0.803)	8.03 (0.155)
[3]	1.037 (0.000)	0.0010 (0.977)	23.20 (0.002)
[4]	1.011 (0.000)	-0.0010 (0.742)	26.97 (0.005)

Note: The *p*-values (in parentheses) corresponding to the estimates of β and λ are for the null hypotheses that these parameters are zero.

4.2 Hybrid model estimates

Estimation of the hybrid specification is based on the following structural form:

$$\pi_t = \lambda \left(\frac{1}{(1 - \eta\mu)} \right) mc_t + \gamma_f E_t \pi_{t+1} + \gamma_b \pi_{t-1},$$

where

$$\lambda = \left(\frac{(1 - \omega)(1 - \theta)(1 - \theta\beta)}{\theta} \right) \phi^{-1},$$

$$\gamma_f = \beta\theta\phi^{-1},$$

$$\gamma_b = \omega\phi^{-1},$$

$$\phi = \theta + \omega[1 - \theta(1 - \beta)].$$

We consider three estimators. First, the corresponding reduced form is estimated by instrumental variables (a two-stage least squares), and structural parameter estimates are then derived from the reduced-form estimates. Second, GMM estimation is performed based on the following orthogonality conditions:

$$E_t \left[\left(\pi_t - \beta\theta\phi^{-1} \pi_{t+1} - \left(\frac{(1 - \omega)(1 - \theta)(1 - \theta\beta)}{\theta} \right) \phi^{-1} \kappa mc_t - \omega\phi^{-1} \pi_{t-1} \right) Z_t \right] = 0.$$

Note that GMM estimation results from the same orthogonality conditions depend on the chosen normalization (Gali and Gertler 1999). On the other hand, the CUE, by construction, is invariant to the choice of normalization. Following Newey and Smith (2001), analytical bias-corrected versions of these three estimators can be computed.

Based on instrument set [4], Table 3 reports reduced-form and structural parameter estimates setting $\kappa = 1$ and $\kappa = 0.13$. Also reported is the average price duration, D (in quarters), corresponding to the estimate of θ .

The estimates are fairly similar across methods of estimation. Forward-looking behaviour is dominant relative to the backward-looking component. The fraction of the backward-looking price-setters differs from zero and is near one-third. The discount factor is still greater than one across specifications and estimation methods. The estimates of the probability of changing price imply an unrealistic duration of price stickiness. The duration lies between 12 quarters and a value as high as 48 quarters. The slope coefficient on marginal cost now has the right sign in all cases. However, it is never significantly different from zero. Finally, the overidentifying restrictions are not rejected, but only marginally.⁹ Thus, the results based on the Cobb-Douglas production technology suggest that the real marginal cost is not a significant determinant of inflation, which refutes the theoretical predictions. These results stand in contrast to Gagnon and Khan (2001), who find evidence supporting the New Phillips curve in Canada. In particular, they never reject the hybrid specification.

Table 4 reports the results for a Cobb-Douglas production function with overhead labour. In this case, the real marginal cost is given by:

$$mc_t = s_t + bh_t,$$

where

$$b = \frac{\bar{H}/H}{1 - \bar{H}/H}.$$

The series for hours worked is constructed as the number of employees multiplied by the average hours worked per quarter.¹⁰ The resulting series is stationary around a stable mean. In contrast with the series used by Sbordone (2001) and Gagnon and Khan (2001), no detrending is needed.

9. The overidentifying restrictions test rejects for all cases with the instrument set [3] at the usual 5 per cent level.

10. The average hours worked per quarter are calculated by multiplying the average hours worked per week by 13.

Table 3
Hybrid Phillips curve estimates: Cobb-Douglas

κ	Method	θ	β	λ	ω	γ_f	γ_h	D	J-stat.
1	IV	0.951	1.008	0.0004	0.337	0.743	0.261	20.53	17.09
		(0.041)	(0.022)	(0.003)	(0.092)	(0.055)	(0.055)	(17.44)	
		[0.000]	[0.000]	[0.871]	[0.000]	[0.000]	[0.000]	[0.242]	[0.072]
	GMM	0.969	1.001	0.0004	0.389	0.713	0.287	32.01	17.28
		(0.081)	(0.025)	(0.002)	(0.106)	(0.057)	(0.056)	(82.72)	
		[0.000]	[0.000]	[0.853]	[0.000]	[0.000]	[0.000]	[0.700]	[0.068]
	CUE	0.979	1.002	0.0002	0.398	0.713	0.287	48.66	17.11
		(0.250)	(0.040)	(0.005)	(0.120)	(0.068)	(0.065)	(79.15)	
		[0.000]	[0.000]	[0.967]	[0.001]	[0.000]	[0.000]	[0.934]	[0.072]
0.13	IV	0.913	1.007	0.0033	0.323	0.743	0.261	11.40	17.10
		(0.020)	(0.022)	(0.020)	(0.104)	(0.055)	(0.055)	(26.19)	
		[0.000]	[0.000]	[0.870]	[0.004]	[0.000]	[0.000]	[0.664]	[0.072]
	GMM	0.917	1.001	0.0034	0.368	0.713	0.287	12.03	17.28
		(0.201)	(0.024)	(0.020)	(0.119)	(0.056)	(0.056)	(29.57)	
		[0.000]	[0.000]	[0.850]	[0.003]	[0.000]	[0.000]	[0.685]	[0.068]
	CUE	0.928	1.002	0.0024	0.376	0.712	0.288	14.04	17.11
		(0.471)	(0.036)	(0.003)	(0.167)	(0.071)	(0.066)	(93.01)	
		[0.051]	[0.000]	[0.944]	[0.025]	[0.000]	[0.000]	[0.880]	[0.072]

Notes: Standard errors are in parentheses; p -values are in square brackets.

Table 4
Hybrid Phillips curve estimates: Cobb-Douglas and overhead labour

κ	Method	θ	β	λ	ω	γ_f	γ_h	D	J-stat.
1	GMM	0.879	1.001	0.0056	0.478	0.645	0.352	8.26	28.59
		(0.029)	(0.039)	(0.004)	(0.078)	(0.045)	(0.040)	(2.01)	
		[0.000]	[0.000]	[0.146]	[0.000]	[0.000]	[0.000]	[0.000]	[0.012]
	CUE	0.858	0.926	0.010	0.533	0.585	0.393	7.02	25.26
		(0.062)	(0.159)	(0.012)	(0.127)	(0.109)	(0.078)	(3.05)	
		[0.000]	[0.000]	[0.422]	[0.000]	[0.000]	[0.000]	[0.022]	[0.029]
0.13	GMM	0.718	1.001	0.044	0.391	0.648	0.352	3.548	28.59
		(0.068)	(0.033)	(0.029)	(0.066)	(0.044)	(0.040)	(0.853)	
		[0.000]	[0.000]	[0.138]	[0.000]	[0.000]	[0.000]	[0.000]	[0.012]
	CUE	0.607	0.902	0.122	0.355	0.582	0.377	2.54	23.93
		(0.113)	(0.126)	(0.099)	(0.084)	(0.116)	(0.080)	(0.730)	
		[0.000]	[0.000]	[0.224]	[0.000]	[0.000]	[0.000]	[0.001]	[0.047]

Notes: Standard errors are in parentheses; p -values are in square brackets.

Finally, the instrument set corresponds to the fourth one augmented by four lags of hours worked.

We first tried to estimate the parameter b . Unfortunately, the estimates were never significant. Instead, we report the results obtained with GMM and CUE for a value of b , calibrated as in other empirical studies of the New Phillips curve. Following Rotemberg and Woodford (1999), b is calibrated to 0.4. The estimates of price-stickiness duration are now more plausible, especially for $\kappa = 0.13$. The discount factor is now less than one in the case of estimation by CUE. The forward-looking component still dominates, but now the fraction of backward-looking price-setters is more important for $\kappa = 1$. Here again, the slope coefficient on marginal is never significant, and the specification is rejected in all cases.

We also tried to estimate the specification including the adjustment cost of labour based on equation (6). Labour is measured as explained above and the instrument set is the same as for estimation of the previous model specification. The parameter ϕ was never significant across estimation methods. We then calibrated this parameter following the estimates reported by Ambler, Guay, and Phaneuf (1999). The estimation results were not significantly different from the ones based on a Cobb-Douglas production function without adjustment cost.

4.3 Open economy

We proceed to estimate the hybrid specification with real marginal cost augmented by the terms of trade as in equation (7). The terms of trade are calculated as the logarithm of the import price minus the logarithm of the domestic GDP deflator. Instrument set [4] augmented with four lags of the terms of trade is used.

In this case as well, the relative coefficient to the terms of trade is never significant. Table 5 reports estimates obtained with CUE for $\kappa = 0.13$. The parameter of openness, Θ , has a point estimate, which seems to be in accordance with the degree of openness of the Canadian economy, but it is not statistically significant. The other results are similar to previous ones and again the specification is decisively rejected. The addition of the terms of trade in the instrument set results in an important increase in the value of the overidentifying restrictions test statistic. This suggests that the terms of trade could be an important explanatory variable for Canadian inflation.

The results are similar when we replace the terms of trade in the specification of real marginal cost by the real exchange rate. The parameter relative to the real exchange rate is estimated imprecisely, and the overidentifying restrictions test clearly rejects the model in all cases.

Table 5
Hybrid Phillips curve estimates: Open economy with terms of trade

Method	θ	β	λ	α	Θ	γ_f	γ_b	D	J -stat.
CUE	0.939 (0.467) [0.047]	0.999 (0.066) [0.000]	0.0011 (0.019) [0.952]	0.528 (0.254) [0.040]	0.303 (9.02) [0.999]	0.640 (0.041) [0.000]	0.359 (0.030) [0.000]	16.49 (127.20) [0.897]	35.86 (0.000)

Notes: Standard errors are in parentheses; p -values are in square brackets.

5 Discussion

The estimation strategy advocated in this paper allows us to obtain estimates of New Phillips curves, which do not depend on the normalization of the moment conditions. Furthermore, the implementation of bias-corrected estimators mitigates the well-known problem in IV methods of a bias effect that increases with the number of moment conditions. When applied to Canadian data, the bias-corrected estimator results in more importance being given to the forward-looking relative to the backward-looking component in the hybrid version New Phillips curve compared with the GMM estimates obtained by Gagnon and Khan (2001).

In contrast with other empirical studies,¹¹ the specification test based on overidentifying restrictions rejects the New Phillips curve and its hybrid version for almost all specifications considered in this paper. The estimation of the weighting matrix is crucial for the small sample properties of Hansen's (1982) specification test, especially when the number of moment conditions is important relative to the number of observations.¹² These studies fixed at arbitrary values the number of lags used in kernel estimation of the weighting matrix. In this paper, we adopt a data-dependent automatic lag selection procedure, and the estimation of the weighting matrix is based on sample moments in deviation. This approach improves the power of the overidentifying restrictions test in small samples.¹³

11. Balakrishnan and López-Salido (2002); Gagnon and Khan (2001); Galí and Gertler (1999); Galí, Gertler, and López-Salido (2001a); Galí, Gertler, and López-Salido (2001b); and Galí and López-Salido (2001).

12. For some of these studies, the ratio of the number of moment conditions to the number of observations equals one-third.

13. Similar remarks hold for the econometric investigation of the New Phillips curve for U.S. inflation (see Guay and Luger 2002).

Conclusions

The rejection of alternative specifications of the New Phillips curve suggests that a richer dynamic structure in the explanatory variables will be needed to capture the dynamics of Canadian inflation. In the case of the United States, Kurmann (2002) also finds considerable uncertainty between the observed persistent movements in inflation and what is predicted by a New Phillips curve model. His results and those of this paper represent an important step back from the conclusions of previous authors who argue that New Phillips curve models are a good representation of inflation dynamics. These new results suggest that, at the theoretical level, richer versions of the structural model from which the New Phillips curve is derived would need to be developed. Mankiw and Reis (2002) proposed a "sticky-information"-based Phillips curve that can generate inflation dynamics similar to what is observed in the data. However, assessing the empirical relevance of that model raises several other econometric issues that go beyond the scope of this paper.¹⁴

14. Khan and Zhu (2002) report estimates of the "sticky-information"-based Phillips curve. However, their inference method suffers from a generated regressor problem of the type mentioned above.

Appendix

Data Description

When applicable, the final series is in quarterly frequency, seasonally adjusted, at annual rates, and in millions (of dollars or persons), unless otherwise indicated. The series codes are from Statistics Canada's CANSIM database.

1. Total GDP deflator: constructed from the following series.
 - Nominal GDP = V498086
 - Constant dollar GDP = V1992259
 - Chained dollar GDP = V1992067
2. Labour income share
 - $Ishare = \text{wages and salaries} / \text{total GDP} = V498076 / V498074$
 - $Ishare_{tax} = \text{wages and salaries} / (\text{total GDP} - \text{indirect taxes less subsidies on factors of production and on products})$
 $= V498076 / (V498074 - V1992216 - V1997473)$
 - $Ishare_{inc} = (\text{wages and salaries} + \text{income of non-farm unincorporated business}) / (\text{total GDP} - \text{indirect taxes less subsidies on factors of production and on products})$
 $= (V498076 + V498081) / (V498074 - V1992216 - V1997473)$
 - $Ishare_{nfb} = (\text{all industries wages and salaries} - \text{farm wages and salaries} - \text{public wages and salaries}) / (\text{all industries GDP} - \text{farm GDP} - \text{public GDP})$

Note: $Ishare_{nfb}$ is constructed from CANSIM Table 379-0006 (GDP at factor cost), 382-0001 (old table for wages and salaries), and 382-0006 (new table for wages and salaries).

3. Import prices: constructed from the following series.
 - Nominal imports = V498106
 - Constant dollar imports = V1992253
 - Chained dollar imports = V1992063
4. Hours worked
 - Average hours worked per week, all industries = LSA2050 (Bank of Canada series code)

5. Employment

- Total employment, 15 years old and above = D767608 and V2062811
- Private sector employment = total employment - V2066969

6. Population

- Population, 15 years old and above = D767284 and V2091030

7. Nominal exchange rates

- Canadian dollar/U.S. dollar closing rate = B3414 (monthly frequency, a quarter is the average of three months)

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Discussion

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In this paper, the authors investigate the empirical relevance of the New Keynesian Phillips curve (NKPC) for Canada. The importance of this investigation is obvious. Such empirical evidence can allow us to distinguish between various theories of inflation dynamics, which in turn have crucial policy implications. For instance, the importance of the forward-looking component of inflation determines the size of disinflation costs and how monetary policy should achieve low inflation.

As suggested by recent developments in the econometric literature, important issues are involved in the estimation of the NKPC. The paper's main contribution is to provide a careful econometric analysis—the most extensive to date in this context—that acknowledges potential shortcomings of the standard Generalized Method of Moments (GMM) estimation approach.¹ The authors provide a useful warning on the application of these techniques and document the robustness of existing results to sensible perturbations in the specification and estimation approach.

Moreover, given the amount of empirical evidence for the United States, another useful contribution of this paper is that it provides further international evidence on the NKPC. International comparisons can deliver interesting insights on the mechanisms that underlie inflation dynamics. For example, different monetary experiences across countries provide an additional source of variation that could eventually help us identify important features of inflation dynamics. The Canadian experience with inflation targeting is interesting in this regard.

1. For the estimation of the NKPC, I use "standard GMM" estimation to refer to previous implementations of GMM.

The main conclusion of this paper is that the New Keynesian Phillips curve is not supported in Canada. The goal of my discussion is to better understand what might be driving the results and their implications for the health of the NKPC in Canada. In particular, I will organize my discussion around two questions.

- (i) How important are the econometric issues highlighted by the authors in explaining their results?
- (ii) How should we interpret the results and the fact that a specification of the NKPC is statistically rejected?

What Is the Importance of the Econometric Issues?

As has been shown theoretically and in the context of other applications, standard GMM techniques potentially suffer from significant shortcomings. This paper sets out to address some of these in the context of the estimation of the NKPC. In the end, therefore, it is important to know how significant these econometric issues are for this application.

The authors discuss several weaknesses. First, standard GMM estimation suffers from an asymptotic bias when a large number of instruments are used to estimate overidentified models.² Another issue concerns the number of lags used in the construction of the Newey-West estimator of the variance-covariance matrix of the moments. In many applications, the results are sensitive to this choice. Finally, there is a power issue involved with the typical implementation of the test of overidentifying restrictions. This leads the authors—based on the results of Newey and Smith (2001)—to consider bias-corrected versions of the instrumental variable (IV) and GMM estimators, and for the non-linear specification, the bias corrected version of the continuously updating estimator of Hanson, Heaton, and Yaron (1996). Moreover, they use a modification of the test of overidentifying restrictions, proposed by Hall (2000), which is known to improve its power.

All three estimators and all specifications considered by the authors yield similar results: a large forward-looking component, between 0.582 and 0.743 depending on the specification, and a positive but statistically insignificant coefficient on the marginal cost measure. For the specification using the Cobb-Douglas production function, all three estimators give essentially the same results. The overidentifying restrictions are rejected at the 10 per cent level in all cases.

2. The estimation of the optimal linear combinations of the moments (and weighting matrix) is an important source of bias.

How do these estimates compare with those obtained from standard GMM? Since all the estimates reported in the paper are, to some extent at least, accounting for the shortcomings of standard GMM, the answer is not clear. The authors do provide Monte Carlo results for an ARMA(1,1) process to show the adverse effect of increasing the number of instruments. They also illustrate the sensitivity of the Gali and Gertler (1999) results to alternative numbers of lags in the estimation of the Newey-West weighting matrix. But, while indicative, it is not obvious how these results extend to NKPC estimation performed in the paper. How important are the shortcomings for this specific application; which one is more important; and how unreliable would standard GMM be in this context? We therefore do not know the extent to which the authors' conclusion is the result of their more accurate econometric analysis.

Gagnon and Khan (2001), however, did estimate a similar NKPC for Canada, using similar data and the standard GMM techniques. As such, their results serve as a useful benchmark. Interestingly, they reach the same conclusion for the relationship between inflation and the output-gap measure: positive but insignificant (at the 5 per cent level).³ The main difference is that Gagnon and Khan estimate a much smaller degree of forward-looking behaviour: their estimate of γ_f is 0.492, compared to 0.713 for the comparable specification in Guay, Luger, and Zhu. This is a sizable difference. Overall, however, it seems that, if anything, the authors' results are more favourable to the NKPC than the Gagnon and Khan results based on the standard GMM techniques.

Importantly, the authors' rejection of the NKPC does not appear to be driven by their improved econometric approach. And using standard GMM would yield the same conclusion.

How Should This Evidence Be Interpreted?

As the empirical literature has shown, inflation dynamics appear to be well approximated by a reduced-form model of distributed lags of inflation, π_t , and an output-gap measure (typically detrended GDP or cyclical unemployment), denoted by x_t :⁴

$$\pi_t = a(L)\pi_{t-1} + b(L)x_{t-1} + u_t, \quad (1)$$

3. The point estimate of λ obtained by Gagnon and Khan in the Cobb-Douglas specification ($\kappa = 1$) is 0.011, compared to 0.004 in Guay, Luger, and Zhu.

4. Other variables could also potentially be part of this reduced-form specification. See, among others, Staiger, Stock, and Watson (2001).

where $a(L)$ and $b(L)$ are p^{th} order polynomial in the lag operator, L . Interestingly, this equation is also satisfied for Canada if the marginal cost is used as the measure of the output gap. In fact, estimating equation (1) on the same data set as Guay, Luger, and Zhu and selecting the lag length using the Schwarz information criterion, ($p = 3$), yield the following estimates in Table 1.⁵

Table 1

a_1	a_2	a_3	b_1	b_2	b_3
0.398	0.177	0.127	-0.328	0.222	0.293
(0.090)	(0.251)	(0.095)	(0.391)	(0.091)	(0.239)

In particular, the coefficient of the second lag of marginal cost, b_2 , is statistically significant. More generally, this marginal-cost measure appears to Granger cause inflation: the p -value of the Granger causality test is 0.05. These reduced-form results provide evidence of a statistically significant relationship between inflation and marginal cost in Canada. This is an important fact that we need to keep in mind while interpreting the authors' results.

To what extent is the NKPC consistent with the reduced-form expression just estimated? The simplest version of the NKPC stipulates that the structural relationship between inflation and a measure of the output gap should take the following form:⁶

$$\pi_t = \lambda mc_t + \gamma_f E_t \pi_{t+1}, \quad (2)$$

where mc_t is the marginal cost. A key feature of this variant of the NKPC is that inflation should have no backward-looking element or equivalently, should display little sluggishness. An important policy implication is that there should be no cost associated with credible disinflation.

However, this simple specification does not adequately capture the degree of persistence that inflation displays. An empirically relevant specification requires adding backward-looking elements, which leads to the hybrid NKPC:

$$\pi_t = \lambda mc_t + \gamma_f E_t \pi_{t+1} + \gamma_b \pi_{t-1}. \quad (3)$$

5. Standard errors are given in parentheses.

6. See Roberts (1995), Woodford (1996), and Clarida, Gali, and Gertler (2000).

The inclusion of the last term can be theoretically motivated in various ways. One approach, as in Galí and Gertler (1999), is to assume that a fraction of the price-setters are following backward-looking rule of thumb. An alternative, as in Christiano, Eichenbaum, and Evans (2001), Woodford (2002), and Boivin and Giannoni (2003), is that price-setters are following some indexing rules when they are not selected—in the Calvo set-up—to optimally change their price.⁷

Given an estimated hybrid NKPC, the question is what constitutes evidence in favour of the NKPC? First, once we acknowledge the possibility of backward-looking elements, it is not clear how important the forward-looking component has to be to provide evidence in favour of the NKPC. But clearly, the presence of a significant forward-looking component has been interpreted in the literature as probably the most important testable implication of the NKPC. Second, the NKPC emphasizes a relationship between inflation and a measure of the marginal cost, captured by λ . Theoretically, this parameter should be positive, but there is no theoretical prediction on how large it should be. But finding a statistically significant positive estimate of λ would certainly provide support to the NKPC.

Although the authors conclude that the NKPC is not supported in Canada, I would argue that the evidence is mixed. First, looking at their Tables 3, 4, and 5, the forward-looking component is always found to be more important than the backward-looking component. In fact, in many cases the point estimate of γ_f is larger than what has been reported in previous studies.⁸ Since the size of γ_f is a key discriminating implication of the NKPC, this result in itself should be seen as very good news for the NKPC in Canada. Second, the estimate of the relationship between inflation and the output-gap measure, λ , has the right sign. But the problem, as the authors emphasize, comes from the fact that the estimate of λ is not found to be significant. This, together with the rejection of the overidentifying restrictions, constitutes the basis of their rejection of the NKPC for Canada.

But this absence of a statistical relationship between inflation and the marginal cost is in itself a puzzling result. Taken literally, and assuming that the specification of the hybrid NKPC nests the truth, it implies that inflation alone should be sufficient to model its dynamics. But this seems at odds with the estimate of the reduced-form Phillips curve presented above: the estimate of equation (1) shows a significant relationship between inflation

7. The inflation indexing leads to a hybrid NKPC of exactly the same form as the backward-looking price-setters, except that the restrictions on the underlying structural parameters and on the size of b are different. But that is immaterial for our discussion.

8. As already mentioned, Gagnon and Kahn (2001) report smaller estimates of γ_b .

and lags of the same marginal-cost measure, which is further supported by the Granger causality test.

This apparent inconsistency suggests the existence of a relationship between inflation and marginal cost, but the structure of the NKPC considered does not properly capture it. Rejecting the NKPC on the basis of this evidence thus requires believing that the NKPC specification considered encompasses all sensible variants consistent with the NKPC paradigm.

But this is not obviously the case. In particular, one could think of slight and sensible perturbations of the NKPC that could favourably alter the timing between inflation and marginal cost. An example of such a perturbation would be to assume that price-setters do not have access to the most current information when re-optimizing their price, as in Rotemberg and Woodford (1997); Christiano, Eichenbaum, and Evans (2001); and Boivin and Giannoni (2003), among others. This would imply that only lags of the marginal cost and inflation should be used as instruments in the estimation.⁹ Other features of the structural model could also alter the form of the Phillips curve. For instance, the presence of habit formation in consumption¹⁰ would change the nature of the theoretical relationship between marginal cost and output gap, and some forms of habit formation could even imply the presence of leads and lags of the marginal cost in the NKPC. These are all variants that have already been considered in the literature and could arguably be part of a legitimate specification of a full-fledged New Keynesian model.

Conclusions

In the end, is the NKPC supported in Canada? If by NKPC we limit ourselves to the specific hybrid form considered in this paper, we have to concur with the authors, and conclude that there is no unambiguous support for this specification. In fact, the same conclusion emerges from other results for Canada, including those of Gagnon and Khan (2001).

However, as I have attempted to emphasize, there are interesting puzzles in the authors' results. On the one hand, they find a large forward-looking component, which is favourable evidence for the NKPC. On the other hand, the failure of the NKPC comes essentially from the lack of statistical

9. This is not the version of the NKPC discussed by the authors. However, in their implementation of the estimation, it seems they do not use current values of the instruments. So their implementation could be closer to this specification. The point, however, is that these timing assumptions are not necessarily innocuous.

10. See, for example, Amato and Laubach (2001) and Boivin and Giannoni (2003).

significance of the contemporaneous relationship between inflation and the output-gap measure.

Given the statistically significant relationship between inflation and the marginal-cost measure found in the reduced-form Phillips curve, the specific structural relationship embedded in the NKPC considered in this paper is crucial to the results. But does the New Keynesian theory hinge so dramatically on this exact relationship? This is not clear. The authors' results are thus providing an important motivation to seriously investigate the implications, for the NKPC specification, of the various ingredients that have been recently added to the workhorse New Keynesian model.

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General Discussion*

In response to the discussant's comments, Alain Guay emphasized that the authors do not think that their results imply that the New Keynesian Phillips Curve (NKPC) is dead, but rather that further research is required.

Hashmat Khan noted that the generalized method of moments (GMM) and the continuous updating estimator (CUE) techniques yield quite similar results, and he stressed the importance of the firm's marginal cost to give plausible estimates for duration. Khan went on to say that estimates of the discount factor will be biased upwards if one does not account for the influence of trend inflation; therefore, the authors' results with beta greater than one are not too troubling if viewed in this light.

Gregor Smith stated that the Hall test will, in fact, under-reject the false null. Consequently, given the rejection of the model in this paper, things could be even worse for the NKPC.

Martin Eichenbaum noted that since some U.S. studies have demonstrated that the inflation process may be adequately modelled as a random walk, attempts to model quarterly changes in inflation seem unlikely to yield any substantive results (the same problem would presumably apply for Canadian data).

Michael Woodford commented that the small positive, but statistically insignificant, parameter estimates for the marginal cost variable did not imply an outright rejection of the NKPC, but could still be consistent with the model.

* Prepared by Stephen Tapp and André Binette.

Guay agreed with Woodford and expressed hope that future theoretical developments would help to find a more satisfying or parsimonious specification. Guay acknowledged that forecasting with the authors' current specification of the NKPC does not outperform a simple random-walk process for inflation, so again, improvements are needed. In response to Smith's comment, Guay said he knew that the test is more powerful; however, he didn't perform any simulations for the level of the test because he felt from his previous work that the level of the test was appropriate. He agreed, however, that Smith's point was valid, and the authors could look into it.

Richard Luger disagreed with Eichenbaum's earlier comment and stated that the Gali-Gertler purely forward-looking specification of inflation dynamics can be rewritten as a backward-looking process and that this is not inconsistent with a rear unit-root process.

Jean Boivin reiterated his view that since similar results could be derived using standard GMM estimation, as opposed to the authors' CUE estimator, the results were more likely a facet of the data than an outcome of the CUE technique.

Section 2:

The Labour Market and Price Adjustment



The Effects of Shocks in a Monetary Business Cycle Model with Unemployment

*Michelle Alexopoulos**

Introduction

Limited-participation models generally require agents to have high labour-supply elasticities to reproduce the high variation of employment and low variation of real wages over the business cycle.¹ This assumption, however, is at odds with microeconomic evidence indicating that labour-supply elasticities for workers are usually low.² Many researchers have suggested that incorporating labour market frictions into this type of model may help the model account for the behaviour of wages and employment without having to rely on assumptions that are at odds with the microeconomic estimates. This paper examines whether embedding imperfectly observed effort into a standard limited-participation model can help the model reproduce the behaviour of wages and employment over the business cycle. This friction is chosen in part because of the empirical evidence in support of the shirking efficiency wage theory in the United States and Canada.³

1. See, for example, Christiano, Eichenbaum, and Evans (1997); Gust (1997); and Rotemberg and Woodford (1996).

2. According to studies such as MaCurdy (1981), Card (1991), and Pencavel (1986), the labour-supply elasticity of males is near zero in the United States.

3. For example, see Gera and Grenier (1994), Blanchflower and Oswald (1994), and Campbell (1989) for the Canadian evidence, and Alexopoulos (2000) and Katz (1986) for an overview of the U.S. evidence.

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The monetary business cycle model examined in this paper has three main features: (i) households make nominal savings decisions before seeing the values of the period's shocks; (ii) firms only imperfectly observe their workers' effort levels; and (iii) detected shirkers forgo a bonus. The first two features are common in limited-participation models and Shapiro-Stiglitz (1984) style shirking efficiency wage models, respectively. However, the assumption that detected shirkers forgo a bonus is a departure from the standard Shapiro-Stiglitz efficiency wage model.

Papers such as Alexopoulos (2000, 2002), Felices (2001), and Burnside, Eichenbaum, and Fisher (2000) have explored how this type of model fits the facts in the U.S. economy. This paper focuses on determining whether this model has the ability to explain the presence of involuntary unemployment and the behaviour of wages and employment in the Canadian economy.

The findings suggest that the estimated versions of the model with imperfectly observed effort generally produce smaller variations in wages alongside large variations in employment than the standard limited-participation model. Moreover, in contrast to the standard limited-participation model, the new model's ability to produce large employment variation alongside small wage variation does not depend on high levels of markups or large labour-supply elasticities. The model with partial income insurance produces lower wage variation and larger employment variation than the model with full income insurance. However, both versions of the efficiency wage model can reproduce the wage and employment variation in Canada better than the standard limited-participation model once capital adjustment costs are introduced.

In addition to being able to reproduce the wage and employment behaviour, the model's responses to technology shocks, as well as monetary and fiscal policy shocks, are qualitatively consistent with empirical evidence in the United States and Canada.⁴ Following a contractionary monetary policy shock, real output, employment, consumption, investment, profits, and real wages fall, and interest rates rise. Moreover, following an expansionary fiscal policy shock, output, employment, and investment increase, while real wages, consumption, and prices fall. These qualitative responses do not depend on the nature of risk-sharing arrangements between workers. However, the amount of risk-sharing available to agents affects the magnitudes of the responses. For example, in response to a monetary policy

4. See Christiano, Eichenbaum, and Vigfusson (2002); Ramey and Shapiro (1998); Edelberg, Eichenbaum, and Fisher (1998); Christiano, Eichenbaum, and Evans (1997, 1998); and Sims and Zha (1996) for the U.S. evidence, and papers such as Cushman and Zha (1997) and Fung and Gupta (1997) for Canadian evidence.

shock, the model with partial income insurance produces a much larger employment response and a smaller real-wage response than the model with full income insurance.

All efficiency wage models start with the premise that wages affect a worker's productivity. However, the reason for the link between wages and productivity differs across the various types of efficiency wage models. In my model, and in models following the Shapiro and Stiglitz (1984) tradition, the link between a worker's wage and a worker's productivity emerges because the firm can only imperfectly observe employee effort.⁵ Therefore, when making decisions about effort, wages, and employment, firms take into account their workers' incentive-compatibility (IC) constraints. In equilibrium, firms will offer workers wages and effort levels that ensure that the workers voluntarily provide the optimal effort level.

Shirking efficiency wage models have a number of attractive features. First, they are compatible with positive levels of unemployment, since the optimal wage chosen by firms may not induce them to hire all workers in equilibrium. Second, employment fluctuations represent changes in the number of people working, as opposed to changes in the number of hours worked per person when there is equilibrium unemployment.⁶ Third, employment and wages are determined by the labour-demand curve and the individuals' IC constraints when there is unemployment. Therefore, the behaviour of wages and employment does not depend on the elasticity of the labour-supply curve. Fourth, the model is consistent with evidence suggesting that the prevailing wage rate is inversely related to the level of unemployment.⁷

The model's features give rise to the possibility that introducing a shirking efficiency wage friction into a standard business cycle model may help the model reproduce the behaviour of wages and employment without relying on a high labour-supply elasticity. For example, in a simple efficiency wage model, such as the one presented in Solow (1979), firms choose to offer workers a real wage that is rigid across periods, and unemployment is involuntary. If firms want to increase the size of their workforce in this model, they can simply hire additional employees at the prevailing wage from the pool of unemployed workers. Since employment responds to market conditions while wages are unaffected, this simple model produces

5. In this environment, it is assumed that the monitoring technology is imperfect. This may occur because no perfect monitoring system exists or because the cost associated with implementing a perfect monitoring system is too high for its adoption to be profitable.

6. Lilien and Hall (1986) report that most of the variation in employment hours is accounted for by changes in the number of people employed.

7. See Blanchflower and Oswald (1994).

the same responses as a simple neo-classical model with divisible labour and individuals who have infinite labour-supply elasticity.

Encouraged by the predictions of Solow's simple efficiency wage model, papers such as Danthine and Donaldson (1995), Gomme (1999), and Kimball (1994) have examined the predictions of general-equilibrium Shapiro-Stiglitz shirking efficiency wage models. Following in the tradition of Shapiro and Stiglitz (1984), their models assume that individuals are fired if they are detected shirking on the job. In general, these authors find that their models are unable to generate high employment variation and low real-wage variability. These results are attributable to the assumption that firms fire detected shirkers.⁸ Therefore, this paper incorporates imperfectly observable effort into a monetary model where individuals who are found shirking on the job forgo a portion of their possible pay for the period (i.e., a bonus or a raise), instead of being dismissed.⁹

There are two main reasons why this alternative "monetary punishment" is of interest. First, the evidence presented in Agell and Lundborg (1995), Malcomson (1998), Hall (1993), and Weiss (1990) suggests that firms more commonly rely on this type of "monetary punishment" to discipline workers than on outright dismissal. Second, if firms punish detected shirkers by withholding a bonus, firms can punish shirking workers even when there is full employment in the economy. Consequently, a model with this monetary punishment does not embed the same powerful forces leading to strongly procyclical wages and weakly procyclical employment at low levels of unemployment as do models with the traditional Shapiro and Stiglitz dismissal punishment.

In section 1, I describe the limited-participation model with imperfectly observed effort and a monetary punishment. In section 2, I outline the results for the estimated versions of the model and the empirical implications for the model's second-moment properties of wages and employment for Canada. I present the estimated model's responses to technology, monetary and fiscal policy shocks, and compare them with the existing evidence on

8. In the model where firms fire detected shirkers at the end of the period, firms must increase the wage paid to workers as the economy moves towards full employment. This occurs because the decrease in the expected duration of unemployment causes the punishment associated with being dismissed to approach zero. This implies that the IC constraint becomes infinitely steep in the model as the unemployment rate approaches zero. Since wages are determined by the intersection of labour demand and the individual's IC constraint, changes in labour demand lead to large changes in the number of people employed and small changes in real wages at low rates of unemployment. Consequently, the model predicts that wages are highly procyclical.

9. This environment is similar to those seen in Alexopoulos (2000); Burnside, Eichenbaum, and Fisher (2000); and Felices (2001).

the economy's responses to these shocks. I then compare the results for the model with imperfectly observed effort with results obtained from a standard limited-participation model with divisible labour. Finally, I conclude and suggest areas for future research.

1 The Model

The description of the model in this section closely follows the model outlined in Alexopoulos (2002).¹⁰ The economy has six sectors: the monetary authority, the financial intermediaries, the government, families and individuals, the final good firms, and the intermediate goods firms.

1.1 The monetary authority

Each period, the monetary authority increases the economy's money supply by transferring X_t units of money to the financial intermediaries. The growth rate of money, x_t , is defined by

$$x_t = \frac{X_t}{M_t} = \frac{M_{t+1} - M_t}{M_t},$$

where M_t is the nominal stock of money at the beginning of period t , and X_t is the amount of the monetary injection. Here, the money stock is assumed to be measured by M2, and x_t is the realization of an AR(1) process:¹¹

$$x_t - \mu_x = \rho_x(x_{t-1} - \mu_x) + \varepsilon_{xt},$$

where μ_x is the mean growth rate of money, and ε_{xt} is a serially uncorrelated process with mean zero and standard deviation σ_x .¹²

1.2 Financial intermediaries

At the beginning of each period, the continuum of perfectly competitive financial intermediaries receives nominal deposits, D_t , from families to

10. Alexopoulos (2002) explores whether a monetary shirking efficiency wage model can explain the observed behaviour of real wages and employment in the U.S. economy.

11. See Christiano, Eichenbaum, and Evans (1998) for a discussion of how a model that uses this exogenous policy is related to a model where monetary policy follows an endogenous policy such as the Taylor rule.

12. This assumption is consistent with the findings of Christiano, Eichenbaum, and Evans (1998), who indicate that x_t follows an AR(1) process if the money stock is measured by M2.

invest for the duration of the period. After D_t is deposited, the financial intermediaries receive the lump-sum monetary injection, X_t , from the monetary authority.

I assume that intermediate goods firms borrow funds from the financial intermediaries to finance their wage bill at a gross interest rate, R_t , as in the standard limited-participation model. It follows that the economy's loan-market clearing condition is:

$$L_t = D_t + X_t, \quad (1)$$

where L_t is the total amount of funds demanded by firms in time period t , and $D_t + X_t$ is the supply of loans available. At the end of each period, the intermediate goods firms repay their loans with interest, and the financial intermediaries distribute $R_t + D_t$ to the households in return for their deposits and $R_t + X_t$ in the form of profits.

1.3 The government

Each period, the government purchases G_t units of the final good. The government finances its purchases by levying lump-sum taxes on families. This implies that the government's period t budget constraint is:

$$G_t \leq Tax_t,$$

where Tax_t is the amount of lump-sum taxes collected. Since all families are identical in the model, each family is assumed to pay the same amount of taxes.

1.4 Families and individuals

In models with unemployment, when individuals' incomes are not fully insured, their incomes are heterogeneous. If an agent can transfer wealth across time periods, his savings decision then becomes dependent on his entire work history. To isolate the role of the imperfect observability of effort and to facilitate a comparison of my model to the standard limited-participation model, I make assumptions that guarantee that the workers' problems will be homogeneous. Specifically, I assume that workers belong to families.¹³

13. Past research has presented two other approaches that ensure that agents' problems are homogeneous. The first method fully insures workers' incomes against unemployment. The second method introduces entrepreneurs into the model. In this case, it is assumed that entrepreneurs are allowed to save and accumulate capital, but workers are not. Versions of my shirking limited-participation model that use these different structures do not yield significantly different results from the model with the family structure.

The economy is populated by a large number of families, each of which contains a $[0,1]$ -continuum of infinitely lived individuals. Individuals do not directly own assets in this model. Instead, it is assumed that each individual's family owns an equal portion of the capital stock, as well as equal shares in the intermediate goods firms and the financial intermediaries. The funds a family receives from its assets are used to pay taxes, invest in capital goods, and purchase some consumption goods for family members.

1.4.1 A representative family

Each period, the family chooses how much to invest in capital, I_t , how much family consumption to purchase, c_t^f , how much cash to deposit in financial intermediaries, D_t , and how much money to carry into the next period, M_{t+1} . Consistent with the limited-participation constraint, the family chooses the level of nominal deposits before the values of the period's shocks are revealed.

After the shocks are revealed, the family pays taxes, Tax_t , and purchases I_t and c_t^f , using their beginning-of-period money holdings, M_t/P_t , and their return on capital, $r_t K_t$. Since profits and the return on deposits are distributed to the family at the end of the period, these funds are unavailable for purchasing period t goods. This implies that the family's cash-in-advance constraint and money holdings are given by:

$$P_t c_t^f \leq M_t - D_t - P_t Tax_t + P_t r_t K_t - P_t I_t, \quad (2)$$

$$M_{t+1} = \left[M_t - D_t - P_t c_t^f - P_t Tax_t + P_t r_t K_t - P_t I_t \right] + R_t [D_t + X_t] + PR_t. \quad (3)$$

Here, PR_t and $R_t X_t$ denote the profits from intermediate goods firms and financial intermediaries in period t , respectively. Since the family distributes c_t^f among the members before firms hire employees, each family member is provided with an equal amount.

As in the standard limited-participation model, it is assumed that the family faces adjustment costs whenever they alter their stock of capital or their flow of funds to the goods market. These adjustment costs are similar to those used in Christiano and Eichenbaum (1992a) and Christiano and Fisher (1998), and cause the effects of monetary policy shocks to be persistent. In particular, it is assumed that each individual spends a portion of his or her leisure time reorganizing the family's purchases, if the flow of funds to the goods market changes. Moreover, the capital-adjustment costs imply that the

end-of-period capital stock, K_{t+1} , is determined by the following technology:

$$K_{t+1} = \left[\gamma_1 I_t^v + \gamma_2 K_t^v \right]^{\frac{1}{v}}. \quad (4)$$

Here, I_t is the amount of period t investment, $v \leq 1$ determines the cost of adjusting the capital stock, and γ_1 and γ_2 are positive constants. Similar to the adjustment costs in Christiano and Fisher (1998), γ_1 and γ_2 are chosen so that the steady-state values of the rental rate of capital and investment are invariant to the level of v . This implies:

$$\gamma_1 = \delta^{1-v} \text{ and } \gamma_2 = (1 - \delta),$$

where δ is the depreciation rate of capital. When $v = 1$, equation (4) reduces to the conventional linear capital-accumulation equation.

1.4.2 Family members

Although individual family members do not have direct access to financial or capital markets, they receive some consumption that is financed by their family's return on financial and capital investments through c_t^f . Family members can increase their consumption levels above c_t^f by seeking employment from the intermediate goods firms. All intermediate goods firms are assumed to have identical production technology. As a result, all firms will offer workers the same wage and require the same level of effort. Since effort is imperfectly observed by the firms, if a worker is hired, that worker must decide whether to provide the level of effort specified in the contract.

Each worker who is hired by an intermediate goods firm receives a one-period contract. This contract specifies the real-wage rate the worker can earn, w_t , the number of hours an employee must work, f , and the effort level the firm requires from the worker, e_t .¹⁴ All workers receive a fraction, s , of their wage bill up front. However, the final payment of $(1 - s)w_t f$ is paid only to workers not disciplined for shirking. Workers all know that if they shirk, firms will detect them with probability $d < 1$.

In addition to the level of c_t^f provided by the family, unemployed family members can purchase extra consumption using the transfer they receive

14. To reduce the amount of notation, the subscript that identifies the different firms is omitted here, since all firms are identical and will choose the same values.

from their family's employment insurance fund, provided that they do not reject a job offer. To finance this family-run insurance program, each employed family member is required to transfer a lump sum, F_t , to their family's employment insurance fund. The total amount collected is then distributed among the unemployed family members during the period. The existence of the employment insurance ensures that individuals who are unemployed will not suffer a large drop in consumption. In this paper, I examine two different risk-sharing arrangements, partial income insurance and full income insurance, to determine the sensitivity of my results to the amount of insurance provided to individuals.

1.4.3 The worker's problem

Employed workers' consumption levels are determined by the level of their family's consumption benefits, c_t^f , and their after-transfer wage income, $w_t - F_t$, while the consumption of the unemployed workers is determined by the level of their families' consumption benefits, c_t^f , and their transfer from the family insurance fund. This implies that c_t , the consumption of non-shirking workers and shirkers who are not detected, c_t^s , the consumption of the detected shirkers, and c_t^u , the consumption of the unemployed are:

$$c_t = c_t^f + w_t f - F_t, \quad (5)$$

$$c_t^s = c_t^f + s w_t f - F_t, \quad (6)$$

$$c_t^u = \begin{cases} c_t^f + \frac{N_t}{1 - N_t} F_t & \text{if the individual had no job offer,} \\ c_t^f & \text{if the individual rejects a job offer,} \end{cases} \quad (7)$$

where N_t represents the total number of family members employed in period t . Individuals' utility levels are then described by the function:

$$u(\tilde{c}_t, \hat{e}_t) = \ln(\tilde{c}_t) + \theta \ln(T - \vartheta(\hat{e}_t > 0)(f\hat{e}_t + \xi)) - \theta \ln(1 + H(Q_t, Q_{t-1})), \quad (8)$$

where $\tilde{c}_t$ is the realized value of the individual's consumption, $\hat{e}_t$ is the level of effort provided to an employer, T is the individual's time endowment, ξ is the disutility associated with providing any effort, and $\vartheta(\cdot)$ is an indicator

function that equals 1 when $\hat{e}_t > 0$, and equals 0 otherwise.¹⁵ The term $-\theta \ln(1 + H(\cdot, \cdot))$ reflects the assumption that each individual spends a portion of his leisure time,

$$\frac{H(\cdot, \cdot)}{1 + H(\cdot, \cdot)},$$

involved in reorganizing the household's flow of funds to the goods market. This assumption guarantees that unemployed family members will spend more time reorganizing the flow of funds to the goods market than their working counterparts in equilibrium. Here, it is assumed that:

$$H(Q_t, Q_{t-1}) = a_0 \left\{ \exp \left[a_1 \left(\frac{Q_t}{Q_{t-1}} - 1 - x \right) \right] + \exp \left[-a_1 \left(\frac{Q_t}{Q_{t-1}} - 1 - x \right) \right] - 2 \right\},$$

where $Q_t \equiv M_t - D_t$. (9)

Therefore, when there are no changes in the flow of funds to the goods market, no adjustment costs are incurred.

After the shocks are realized, all family members attempt to find employment. In the case where firms set wages above the market-clearing level, only a portion of the workers will receive offers of employment and there will be unemployment in equilibrium. Family members who are offered jobs must determine: (i) if they will accept the job; and (ii) whether they will abide by the terms of the contract. Since workers who reject job offers are ineligible for the employment insurance transfer, workers will always accept job offers in this economy. Moreover, the level of effort supplied by a worker is:

$$\hat{e}_t = \begin{cases} e_t & \text{if } e_t \leq \frac{T}{f} \left(1 - \left(\frac{c_t}{c_t^*} \right)^{\frac{d}{\theta}} \right) - \frac{\pi}{f} \\ 0 & \text{if } e_t \geq \frac{T}{f} \left(1 - \left(\frac{c_t}{c_t^*} \right)^{\frac{d}{\theta}} \right) - \frac{\pi}{f} \end{cases}$$

15. Since firms do not perfectly observe effort, they also do not observe whether individuals incur the cost $\frac{\pi}{f}$.

Therefore, an individual will provide the required effort if his IC constraint is satisfied, i.e., if

$$u(c_p, c_f) \geq du(c_p^s, 0) + (1-d)u(c_p, 0) \quad (IC).$$

1.4.4 The family's problem

Each period, firms hire N_t family members. Of these workers, N_t^s are shirkers who exert no effort on the job, and $N_t - N_t^s$ are non-shirkers who each exert an effort level of $\hat{e}_t$. Given the utility function of each of the family members, the form of the adjustment costs, and the definitions of c_t , c_t^s , and c_t^u , the family's problem can be expressed as:

$$\max_{\{c_t^f, K_{t+1}, M_{t+1}, D_t\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \begin{aligned} & (N_t - dN_t^s) \ln(c_t) + dN_t^s \ln(c_t^s) + (1 - N_t) \ln(c_t^u) \\ & + (N_t - N_t^s) \theta \ln(T - f\hat{e}_t - \frac{z_t}{\eta}) + (1 - (N_t - N_t^s)) \theta \ln(T) \\ & - \theta \ln(1 + H(Q_t, Q_{t-1})) \end{aligned} \right\}$$

subject to equations (2) through (4), where:

$$F_t = \begin{cases} (1 - N_t)sw_t f & \text{under partial income insurance} \\ (1 - N_t)w_t f & \text{under full income insurance} \end{cases}$$

In equilibrium, the cash-in-advance constraint holds with equality and firms offer workers wages that induce no one to shirk (i.e., $N_t^s = 0$). Therefore, the family's Euler equations for deposits and capital can be written as:¹⁶

$$E_{t-1} \left\{ \begin{aligned} & \left(\frac{U_{c_t^f}}{P_t} \right) - \theta \frac{H_1(Q_t, Q_{t-1})}{1 + H(Q_t, Q_{t-1})} - \beta \theta \frac{H_2(Q_{t+1}, Q_t)}{1 + H(Q_{t+1}, Q_t)} \\ & - \beta R_t \left[\left(\frac{U_{c_{t+1}^f}}{P_{t+1}} \right) - \theta \frac{H_1(Q_{t+1}, Q_t)}{1 + H(Q_{t+1}, Q_t)} - \beta \theta \frac{H_2(Q_{t+2}, Q_{t+1})}{1 + H(Q_{t+2}, Q_{t+1})} \right] \end{aligned} \right\} = 0$$

and

16. It is assumed that families do not believe that their choices can affect the employment probability of their members. This assumption is made for simplicity. See Alexopoulos (2001) for a more complex model that yields the same allocations.

$$E_t \left\{ U_{c,t} \frac{\partial I_t}{\partial K_{t+1}} - \beta U_{c,t+1} \left(r_{t+1} - \frac{\partial I_{t+1}}{\partial K_{t+1}} \right) \right\} = 0,$$

where

$$U_{c,t} = \frac{N_t}{c_t} + \frac{1 - N_t}{c_t^\eta}$$

$$H_1(Q_t, Q_{t-1}) = \frac{a_1 a_2}{Q_{t-1}} \left\{ \begin{array}{l} \exp \left[a_1 \left(\frac{Q_t}{Q_{t-1}} - 1 - x^1 \right) \right] \\ - \exp \left[-a_1 \left(\frac{Q_t}{Q_{t-1}} - 1 - x^1 \right) \right] \end{array} \right\}$$

$$H_2(Q_t, Q_{t-1}) = -H_1(Q_t, Q_{t-1}) \frac{Q_t}{Q_{t-1}}$$

$$\frac{\partial I}{\partial K_{t+1}} = \delta^{\frac{v-1}{v}} (K_{t+1}^v - (1-\delta)K_t^v)^{\frac{1}{v}-1} K_{t+1}^{v-1}$$

$$\frac{\partial I_{t+1}}{\partial K_{t+1}} = \delta^{\frac{v-1}{v}} (K_{t+2}^v - (1-\delta)K_{t+1}^v)^{\frac{1}{v}-1} (\delta-1)K_{t+1}^{v-1}.$$

1.5 Final good firms

In the economy, the final good, Y_t , is produced and sold to agents by perfectly competitive final good firms. These firms produce Y_t by combining the output of the continuum of intermediate firms according to the following production function:

$$Y_t = \left[\int_0^1 Y_{it}^{\frac{1}{\mu}} di \right]^\mu.$$

Here, Y_{it} represents the input from the i^{th} intermediate firm in period t , and $1 \leq \mu < \infty$ is a measure of substitutability between inputs. This implies that a representative final good firm faces the following problem in period t :

$$\max_{Y_t, \{Y_{it}\}_0^1} P_t Y_t - \int_0^1 P_{it} Y_{it} di \text{ s.t. } Y_t = \left[\int_0^1 Y_{it}^{\frac{1}{1-\mu}} di \right]^{1-\mu}.$$

where P_t is the price of the final good, and P_{it} is the price of the i^{th} intermediate good at time t . The Euler equations from this problem define the demand functions for the output of the intermediate goods firm:

$$Y_{it} = Y_t \left(\frac{P_{it}}{P_t} \right)^{\frac{\mu}{1-\mu}}.$$

This implies that the demand for firm i 's product is increasing in the level of aggregate output, Y_t , and decreasing in the price of its intermediate good, P_{it} . From the demand equations and the zero-profit condition, it follows that the price of the final good is:

$$P_t = \left[\int_0^1 P_{it}^{\frac{1}{1-\mu}} di \right]^{(1-\mu)}.$$

1.6 Intermediate goods firms

The intermediate goods are produced by a $[0,1]$ -continuum of monopolistic competitors, where the i^{th} intermediate good is produced according to the following production function:¹⁷

$$Y_{it} = A_t K_{it}^{\alpha} ((N_{it} - N_{it}^s) f \hat{e}_{it})^{1-\alpha}.$$

Here, $0 < \alpha < 1$, N_{it} , N_{it}^s , and K_{it} denote the number of workers hired, the number of shirkers hired, and the amount of capital rented in period t by firm i , respectively, and A_t is the level of technology, where $\ln A_t = (1 - \rho_A) \ln A + \rho_A \ln A_{t-1} + \varepsilon_{A,t}$, $-1 < \rho_A < 1$, and $\varepsilon_{A,t}$ is a serially uncorrelated process with mean zero and standard deviation σ_A . This function implies that a firm must receive a positive level of effective labour from its workers for production to occur. Each labourer hired by a firm works a fixed shift, f , and provides an effective labour unit input of $f \hat{e}_{it}$, provided the worker does not shirk. The firms rent capital in a perfectly competitive factor market after the values of the shocks are realized, and entry and exit into the production of intermediate good i are ruled out.

17. This form of the production function takes into account that non-shirking workers will provide an effort level of $\hat{e}_{it}$, while shirking workers provide zero effort.

After the shocks are observed, firms publicly advertise how many workers they want to hire, as well as the wage they are willing to pay hired workers and the required effort level from each worker. According to the contract, workers know that they are guaranteed a base salary of $sw_{it}f$ if they accept employment.¹⁸ Furthermore, they know that they will receive an additional payment of $(1-s)w_{it}f$ if they are not detected shirking on the job, and detected shirkers are detected with probability $d < 1$.^{19, 20}

Once the employees are hired, each firm borrows its nominal-wage bill, $P_t w_{it} f N_{it} = W_{it} f N_{it}$, from the bank at the gross interest rate, R_t . Although the firm possesses the funds to pay its entire wage bill before the workers begin production, the firm chooses to withhold a fraction, $(1-s)$, of the funds. This shows the firm's intention to pay the workers while making the punishment for shirking credible.

After production takes place, the output is sold to the final good firms. The firms then pay households for the rental of capital and repay their bank loans with interest. Any remaining funds are then distributed in the form of profits to the families at the end of the period.

A representative intermediate goods firm, hiring identical workers, faces the following problem in period t :

$$\max_{\{P_{it}, w_{it}, N_{it}, K_{it}, e_{it}\}} \{P_{it}(A_t K_{it}^\alpha (f e_{it} N_{it})^{1-\alpha}) - R_t P_t w_{it} f N_{it} - P_t r_t K_{it}\},$$

subject to the period-by-period demand functions:

$$P_{it}^{\frac{\mu}{\mu-1}} (A_t K_{it}^\alpha (f e_{it} N_{it})^{1-\alpha}) - P_t^{\frac{\mu}{\mu-1}} Y_t = 0,$$

18. In this model, s is assumed to be an exogenous parameter. However, the model delivers the same results as a model where: (i) there is a restriction on the minimum value of s , (e.g., a legal restriction or an industry norm); and (ii) s is chosen endogenously by firms. Since firms in this case would set s to its lowest possible level, the exogenous parameter s in the model presented in the paper can be considered this minimum value.

19. In this case, $[1-s]w_{it}$ can be interpreted as a bonus that is paid only to non-disciplined workers.

20. Firms are assumed to never "cheat" by withholding a bonus from a non-shirking worker. This assumption is made for simplicity. The results in this paper are unaffected if the model instead assumes: (i) there are continuing matches between workers and firms that break up with an exogenous probability; (ii) firms get a reputation as bad employers if they do not pay the bonus to non-detected shirkers; (iii) workers will not provide effort to bad employers because they believe that bad employers will fail to provide them with their bonus; and (iv) there are reasonable levels of markups in the economy.

and the period-by-period IC constraints and individual rationality (IR) constraints:

$$u(c_{it}, e_{it}) \geq du(c_{it}^s, 0) + (1-d)u(c_{it}, 0) \text{ (IC)},$$

$$u(c_{it}, e_{it}) \geq u(c_{it}^u, 0) \text{ (IR)}.$$

Here, $u(\cdot, \cdot)$ denotes the representative worker's utility for the period, e_{it} is the effort level specified in the contract, and c_{it} , c_{it}^s , and c_{it}^u are the levels of consumption for a non-disciplined worker, a detected shirker, and an unemployed individual, respectively. Furthermore, w_{it} denotes the real-wage rate offered by the firm, and r_t is the real rate of return on capital.

The IC constraint defines the relationship between effort and wages, since the form of the family's employment insurance implies that the IR constraint does not bind in equilibrium. Using the definitions of c_{it} and c_{it}^s in equilibrium (i.e., equations (5) and (6)), the IC constraint implies that effort is a function of the real wage, the price level, and the intrafamily transfers:

$$e_{it}(w_{it}) = \frac{T}{f} \left(1 - \left(\frac{c_{it}}{c_{it}^s} \right)^{-\frac{d}{\theta}} \right) - \frac{\Sigma}{f},$$

The Euler equations from the firm's problem imply:

$$\frac{e'_{it}(w_{it})w_{it}}{e_{it}(w_{it})} = 1 \text{ (the Solow condition)}$$

$$\frac{Y_{it}(1-\alpha)}{N_{it} \mu} = \frac{P_t}{P_{it}} f w_{it} R_t$$

$$\frac{Y_{it} \alpha}{K_{it} \mu} = \frac{P_t}{P_{it}} r_t$$

$$P_{it}^{\frac{-\mu}{1-\mu}} Y_{it} = P_t^{\frac{-\mu}{1-\mu}} Y_t.$$

The Solow condition demonstrates that the firm's choices will minimize the cost per unit of effort. Given the individuals' utility function, the Solow condition implies that, in equilibrium, wages will be chosen by firms to ensure that:

$$\frac{c_{it}}{c_{it}^s} = \text{const} \Rightarrow e_{it} = \frac{T}{f} \left(1 - (\text{const})^{-\frac{d}{\theta}} \right) - \frac{\xi}{f} = e.$$

Since all of the intermediate goods firms have identical technologies and all workers are identical, all firms choose to offer the same wages and required effort levels to workers. The Euler equations also imply that the firm chooses to set its time t price equal to a constant markup over the period's marginal costs:

$$P_{it} = \mu M C_{it}.$$

Finally, the equilibrium demand for funds can be expressed as:

$$L_t = \int_0^1 W_{it} f N_{it} di,$$

since firms borrow funds from the financial intermediaries to finance their wage bills, $L_t = D_t + X_t$, and no one shirks in equilibrium.

2 The Empirical Results

To estimate the model, growth is introduced by adding an exogenous labour-augmenting technology to the production function as follows:

$$Y_{it} = A_t K_{it}^\alpha (\gamma^t N_{it} f \hat{e}_{it})^{1-\alpha},$$

where $\gamma \geq 1$. In addition, government expenditures are assumed to evolve according to $G_t = \gamma^t \exp(g_t)$, where $g_t = (1 - \rho_g)\mu_g + \rho_g g_{t-1} + \varepsilon_{g,t}$, $-1 < \rho_g < 1$, and $\varepsilon_{g,t}$ is a serially uncorrelated process with mean zero and standard deviation σ_g .²¹

To diagnose the performance of the model, I use a generalized method of moments (GMM) procedure similar to the one described in Christiano and Eichenbaum (1992b). The Canadian data are obtained from the OECD quarterly national accounts, the OECD International Sectoral Database, and Statistics Canada.²²

21. When the process for g_t is estimated, I also include a term, $\tau_g \times t$, to capture the time trend seen in the post-war data.

22. A detailed description of the data is found in Appendix 1, followed by an outline of the exactly identified GMM procedure, based on the Euler equations from the model with technological growth, in Appendix 2.

After the parameters and second moments are estimated, the model is tested by: (i) comparing the estimated second moments from the data to those computed from the model using a Wald test; and (ii) determining whether the model's predictions about how the economy responds to shocks are qualitatively consistent with the empirical evidence.^{23, 24}

Not all of the model's parameters are estimated using the Euler equations. The values for β , T , f , ξ , θ , v , a_1 , and a_2 , are chosen to coincide with values commonly seen in the literature:²⁵

β	T	f	ξ	θ	v	a_1	a_2
$\left(\frac{1}{1.03}\right)^{0.25}$	1.369	1	16	1.5	1	2	2

An additional assumption about the ratio $\frac{c_t}{c_t^s}$ is made to help identify the ratio $\frac{d}{\theta}$, and the parameter s , in the IC constraint. Here, this ratio is assumed to be equal to 1.0526. This value is chosen to ensure that, given the estimated value of $\frac{d}{\theta}$, the percentage of compensation that is given as bonus is approximately 5 per cent.²⁶ The GMM procedure and the data are used to estimate the remaining parameters:

23. This Wald test formally explores the hypothesis that the two sets of estimates are the same in population and is discussed in detail in Christiano and Eichenbaum (1992b).

24. Only single hypotheses are tested given the problems associated with small sample properties of GMM-based Wald statistics. See Burnside and Eichenbaum (1996b) for a discussion of these problems.

25. Since f only affects the scale of effort, it is normalized to 1, T is chosen to coincide with a time endowment of 15 hours per day per quarter, ξ represents a fixed cost of 10 minutes a day, $v = 1$ implies there are no capital-adjustment costs, a_1 and a_2 are set equal to the values in Christiano, Eichenbaum, and Evans (1997), and θ and β are chosen so that they fall in the range commonly seen in the literature. The main findings are robust to small changes in the parameters ξ , θ , v , a_1 , and a_2 .

26. The model's sensitivity was assessed by varying the value of $\frac{c_t}{c_t^s}$, since this value is never observed in equilibrium. In general, the findings indicate that small movements in $\frac{c_t}{c_t^s}$ have little effect on the model's second moments and responses to shocks. The value of $(1-s)$ is consistent with values reported for average bonus in surveys such as ICSA (2001), which included Canadian companies.

$$\left\{ \frac{d}{\theta}, \delta, \tau_g, \mu_g, \rho_g, \sigma_g, \ln(A), \rho_A, \sigma_A, A_y, \ln(\gamma), \alpha, \ln\left(\frac{g}{y}\right), \mu_x, \mu, \rho_x, \sigma_x \right\},$$

in the model, along with the second moments,

$$\left\{ \frac{\sigma_c}{\sigma_y}, \frac{\sigma_i}{\sigma_y}, \frac{\sigma_g}{\sigma_y}, \sigma_n, \sigma_h, \sigma_y \right\},$$

for the detrended data.²⁷ The resulting parameter estimates for each case of the limited-participation model with imperfectly observed effort (herein referred to as the efficiency wage model) are reported in Tables 1 through 3 alongside estimates for a standard limited-participation model with divisible labour for the cases where there are adjustment costs on capital.²⁸ An examination of these estimates reveals that the majority of the predicted values are similar to those commonly seen in the literature.²⁹ The one exception is found in the standard limited-participation model when $v = 0.8$. For this case, the value of the markup and the estimate of α are outside the range usually seen in the literature. However, the finding that a large markup helps the standard model reproduce the wage and employment behaviour in the United States is discussed in Christiano, Eichenbaum, and Evans (1998).

The estimated parameters for the efficiency wage models are virtually identical to those in the limited-participation model, with the exception of the values for θ and $\frac{d}{\theta}$.³⁰ Thus, the differences between the models'

27. A_y is estimated using the condition: $E(\ln(Y_t) - A_y - t \times \ln(\gamma)) = 0$, and $\frac{g}{y}$ is estimated using the condition: $E\left(\ln(G_t) - \ln(Y_t) - \ln\left(\frac{g}{y}\right)\right) = 0$.

The data for the second moments are detrended using a Hodrick and Prescott (HP) filter with $\lambda = 1,600$.

28. The standard limited-participation model with divisible labour is based on Christiano, Eichenbaum, and Evans (1997). See Appendix 3 for details.

29. For example, the estimated markup for the efficiency wage model, μ , is similar to the value of 1.2 reported by Hornstein (1993) and lower than the value assumed in models such as Christiano, Eichenbaum, and Evans (1997) (i.e., $\mu = 1.4$). In addition, the value of α falls within the range [0.25, 0.43] reported in Greenwood, Rogerson, and Wright (1995).

30. For the limited-participation model, the following parameters are estimated:

$$\left\{ \theta, \delta, \tau_g, \mu_g, \rho_g, \sigma_g, \ln(A), \rho_A, \sigma_A, A_y, \ln(\gamma), \alpha, \ln\left(\frac{g}{y}\right), \mu_v, \mu, \rho_v, \sigma_v \right\},$$

where θ is the coefficient on leisure in the individual's utility function.

Table 1
Parameter estimates for the models

Parameter	$v = 1$		
	Estimates		Estimates Standard limited- participation model
	Efficiency wage model (P.I. Case)	(F.I. Case)	
μ	1.2342 (0.0842)	1.2690 (0.0164)	1.2964 (0.0825)
$\ln A$	0.0534 (0.0148)	0.0500 (0.0106)	0.0025 (0.0106)
ρ_A	0.9264 (0.0153)	0.9268 (0.0147)	0.9272 (0.0148)
σ_A	0.0078 (0.0006)	0.0078 (0.0005)	0.0077 (0.0006)
A_y	0.0869 (0.0143)	0.0869 (0.0143)	0.0869 (0.0143)
$\ln(\gamma)$	0.0026 (0.0001)	0.0026 (0.0001)	0.0026 (0.0001)
δ	0.0151 (0.0008)	0.0151 (0.0008)	0.0151 (0.0008)
α	0.3272 (0.0460)	0.3082 (0.0101)	0.2933 (0.0449)
$\ln\left(\frac{g}{y}\right)$	1.4575 (0.0084)	1.4575 (0.0084)	1.4575 (0.0084)
$\frac{d}{\theta}$	0.2338 (0.0160)	0.2393 (0.0047)	n/a
θ	n/a	n/a	1.6060 (0.0922)
ρ_g	0.9717 (0.0148)	0.9717 (0.0148)	0.9717 (0.0148)
τ_g	0.0003 (0.0002)	0.0003 (0.0002)	0.0003 (0.0002)
σ_g	0.0136 (0.0011)	0.0136 (0.0011)	0.0136 (0.0011)
μ_g	1.5219 (0.0279)	1.5219 (0.0279)	1.5219 (0.0279)
ρ_y	0.5529 (0.1121)	0.5529 (0.1121)	0.5529 (0.0761)
μ_y	0.0240 (0.0026)	0.0240 (0.0026)	0.0240 (0.0026)
σ_y	0.0131 (0.0023)	0.0131 (0.0023)	0.0131 (0.0023)

Notes: Standard errors in parentheses.

P.I. = partial income insurance; F.I. = full income insurance.

Table 2
Parameter estimates for the models

Parameter	$v = 0.9$		
	Estimates		Estimates Standard limited- participation model
	Efficiency wage model		
	(P.I.I. Case)	(F.I.I. Case)	
μ	1.2524 (0.0915)	1.2699 (0.0487)	1.2716 (0.0825)
$\ln A$	0.0516 (0.0164)	0.0499 (0.0118)	0.0007 (0.0053)
ρ_A	0.9266 (0.0154)	0.9268 (0.0147)	0.9269 (0.0147)
σ_A	0.0078 (0.0006)	0.0078 (0.0006)	0.0078 (0.0006)
A_v	0.0869 (0.0143)	0.0869 (0.0143)	0.0869 (0.0143)
$\ln(\gamma)$	0.0026 (0.0001)	0.0026 (0.0001)	0.0026 (0.0001)
δ	0.0150 (0.0009)	0.0150 (0.0009)	0.0150 (0.0009)
α	0.3173 (0.0498)	0.3077 (0.0266)	0.3068 (0.0219)
$\ln\left(\frac{g}{y}\right)$	1.4575 (0.0084)	1.4575 (0.0084)	1.4575 (0.0084)
$\frac{d}{\theta}$	0.2377 (0.0168)	0.2400 (0.0095)	n/a
θ	n/a	n/a	1.6315 (0.0517)
ρ_g	0.9717 (0.0148)	0.9717 (0.0148)	0.9717 (0.0148)
τ_g	0.0003 (0.0002)	0.0003 (0.0002)	0.0003 (0.0002)
σ_g	0.0136 (0.0011)	0.0136 (0.0011)	0.0136 (0.0011)
μ_g	1.5219 (0.0279)	1.5219 (0.0279)	1.5219 (0.0279)
ρ_v	0.5529 (0.1121)	0.5529 (0.1121)	0.5529 (0.1121)
μ_v	0.0240 (0.0026)	0.0240 (0.0026)	0.0240 (0.0026)
σ_v	0.0131 (0.0023)	0.0131 (0.0023)	0.0131 (0.0023)

Notes: Standard errors in parentheses.

P.I.I. = partial income insurance; F.I.I. = full income insurance.

Table 3
Parameter estimates for the models

Parameter	$\gamma = 0.8$		
	Estimates Efficiency wage model		Estimates Standard limited- participation model
	(P.I.I. Case)	(F.I.I. Case)	
μ	1.2734 (0.0990)	1.2695 (0.0487)	1.5041 (0.1515)
$\ln A$	0.0496 (0.0165)	0.0500 (0.0136)	0.0274 (0.0174)
ρ_A	0.9269 (0.0151)	0.9268 (0.0147)	0.9310 (0.0129)
σ_A	0.0078 (0.0006)	0.0078 (0.0006)	0.0075 (0.0006)
A_y	0.0869 (0.0143)	0.0869 (0.0143)	0.0869 (0.0143)
$\ln(\gamma)$	0.0026 (0.0001)	0.0026 (0.0001)	0.0026 (0.0001)
δ	0.0148 (0.0009)	0.0148 (0.0009)	0.0148 (0.0009)
α	0.3058 (0.0538)	0.3080 (0.0426)	0.1800 (0.0825)
$\ln\left(\frac{g}{y}\right)$	1.4575 (0.0084)	1.4575 (0.0084)	1.4575 (0.0084)
$\frac{d}{\theta}$	0.2420 (0.0176)	0.2404 (0.0145)	n/a
θ	n/a	n/a	1.4274 (0.0991)
ρ_g	0.9717 (0.0148)	0.9717 (0.0148)	0.9717 (0.0148)
τ_g	0.0003 (0.0002)	0.0003 (0.0002)	0.0003 (0.0002)
σ_g	0.0136 (0.0011)	0.0136 (0.0011)	0.0136 (0.0011)
μ_e	1.5219 (0.0279)	1.5219 (0.0279)	1.5219 (0.0279)
ρ_i	0.5529 (0.1121)	0.5529 (0.1121)	0.5529 (0.1121)
μ_i	0.0240 (0.0026)	0.0240 (0.0026)	0.0240 (0.0026)
σ_i	0.0131 (0.0023)	0.0131 (0.0023)	0.0131 (0.0023)

Notes: Standard errors in parentheses.

P.I.I. = partial income insurance; F.I.I. = full income insurance.

predictions can, in large part, be attributed to the equations and parameters that affect the labour market and adjustment costs.

Next, the models are solved using the estimated parameter values and the linearization technique described in Christiano (1998), and the impulse-response functions are computed for fiscal policy shocks, technology shocks, and monetary policy shocks.

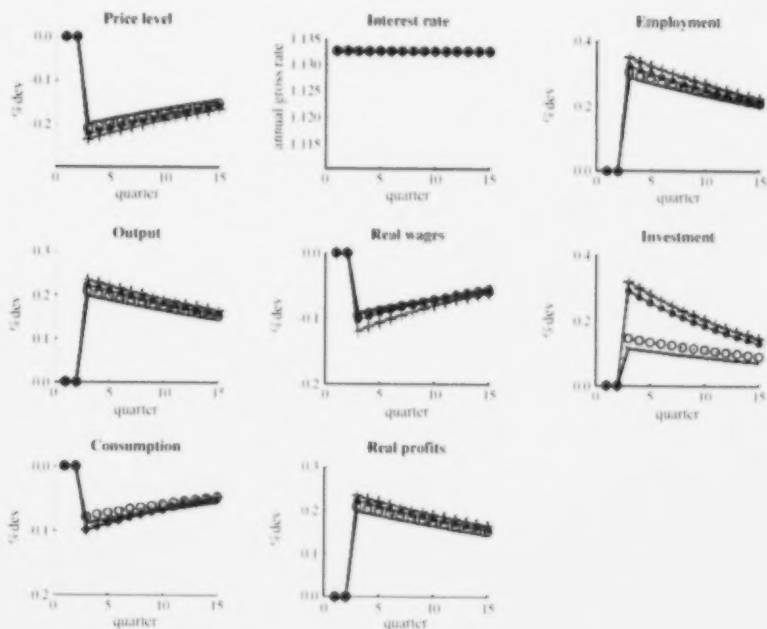
2.1 Fiscal policy shocks

Figure 1 depicts the shirking models' responses to an exogenous increase in government expenditures. Figure 2 illustrates the corresponding responses for the standard limited-participation model. A comparison of these two figures demonstrates that both of the models have the same qualitative predictions for a positive government expenditure shock. In particular, output, employment, investment, and interest rates all increase, while consumption and real wages both decrease. However, neither of the models can account for the observation, seen in Edelberg, Eichenbaum, and Fisher (1998), that prices increase following an exogenous increase in government expenditure.

Figure 1 also demonstrates that the form of the intrafamily transfer and the adjustment cost on capital affect the size of the shirking model's responses to an exogenous fiscal policy shock. In particular, the full income insurance case (— and •—• lines) produces smaller movements than the partial income insurance case (—+— and —o— lines) in all variables except consumption. Furthermore, comparing the model's responses when $\nu = 1$ with the responses of the model when $\nu = 0.8$, shows that an increase in the capital-adjustment costs decreases the shock's effect on all variables. The largest difference can be seen in the efficiency wage model with partial income insurance. When one compares Figures 1 and 2, it is evident that the greatest increase in employment, output, and investment, and the greatest decrease in wages and prices occur in the efficiency wage model with partial income insurance.

The intuition behind these responses is straightforward. In the efficiency wage model, an unexpected exogenous increase in government expenditures initially decreases the amount of money spent on investment and family purchased consumption, holding everything else constant. The fall in c_t^f translates into an increase in the relative consumption of a non-disciplined worker to a disciplined worker, $\frac{c_t^f}{c_t^s}$.

Figure 1
The efficiency wage model's
responses to a positive fiscal policy shock



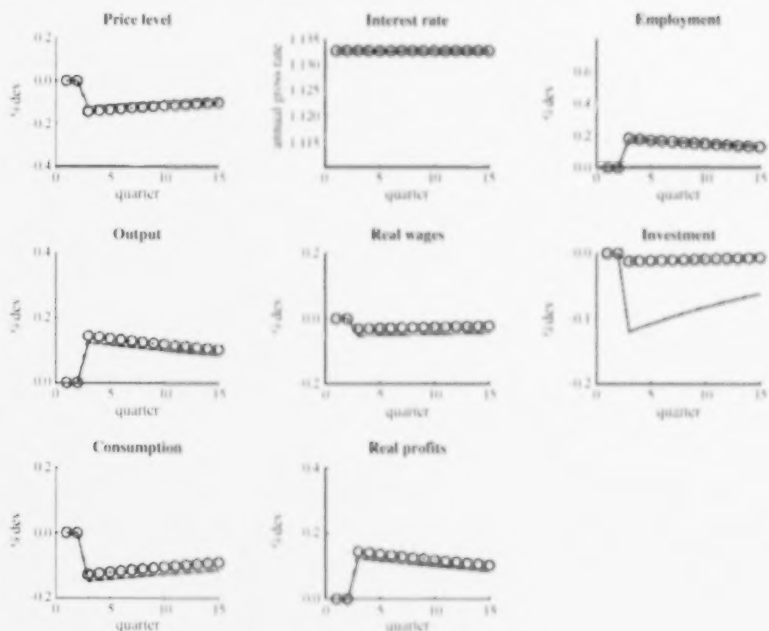
Notes: Partial income insurance, $v = 1.0$: $\circ-\circ-\circ$
 Partial income insurance, $v = 0.8$: $\square-\square-\square$
 Full income insurance, $v = 1.0$: $\bullet-\bullet-\bullet$
 Full income insurance, $v = 0.8$: $\blacksquare-\blacksquare-\blacksquare$
 % dev = percent deviation from steady state.

Therefore, at the previously given real-wage rate and effort level, the utility of a non-shirker is strictly higher than the expected utility of a shirker at this new level of c_t^f . To prevent workers from shirking, firms lower the real wage offered to workers to the point where workers are once again indifferent between providing effort and shirking, i.e., to the point where

$$\frac{c_t^f}{c_t^s} = \text{const.}$$

At this new lower wage, the marginal product of labour exceeds the marginal cost, so firms optimally increase the number of workers they hire.

Figure 2
The standard limited-participation
model's responses to a positive fiscal policy shock



Notes: Limited participation, $v = 1.0$ ———
 Limited participation, $v = 0.8$ - - - - -
 % dev = percent deviation from steady state.

Since the equilibrium effort level remains the same and the number of effective labour hours increases, output rises.³¹

The increase in output has two effects. First, it causes the price of the final good to decline. Second, it causes both the current and expected return on capital to rise. The decrease in prices and the increase in the return on capital allow each family to increase the amount of goods they purchase. However, the precise effect of these changes on c_t^i depends on how investment responds to the shock. For example, when the rise in government expenditures is persistent, families invest more in capital goods because of the large increase in the expected future return on capital. In this case, most

31. This is feasible as long as the economy initially contains enough unemployed workers to meet the firms' extra demand.

of the increase in the family's purchasing power is devoted to investment, and the change in c_t^f is small.

In practice, c_t^f decreases in the model because of the size of the increase in investment and taxes. As a result, real wages decline and firms hire more workers in response to the shock. This causes output to increase and prices to decline. Finally, interest rates do not initially respond to the shock because the level of nominal deposits is determined in advance of the shock and there is no increase in the stock of money.

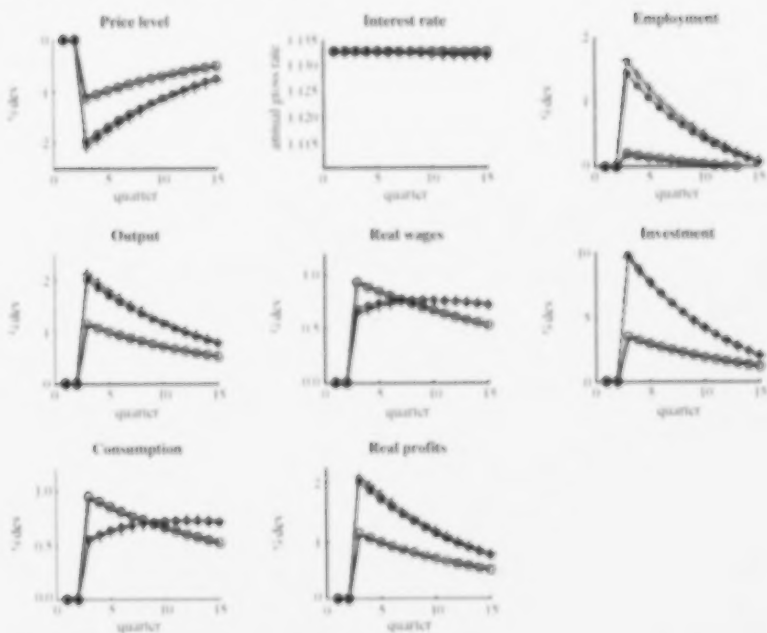
2.2 Technology shocks

Figure 3 displays the efficiency wage model's responses to a shock that increases the level of technology by 1 per cent, and Figure 4 displays the same responses for the standard limited-participation model. These figures show that, in both models, a positive technology shock causes prices to decrease and all other variables to increase.³² Figure 3 demonstrates that: (i) limiting the amount of income insurance available to agents will increase the employment and output responses; and (ii) increasing the costs of adjustment on capital dampens the positive effect of the shock on output, employment, and investment, and increases the effect of the shock on wages and consumption. A comparison of Figures 3 and 4 highlights the differences in the magnitudes of the models' responses. I find that in the efficiency wage model, the price decrease is larger, real wages increase slightly less, and the employment, output, investment, and consumption responses are generally larger.

These responses follow from the fact that a positive technology shock increases both output and the marginal product of labour for firms in the efficiency wage model. The increase in current output has two effects. First, it decreases the price of the final good, which causes an increase in the purchasing power of the family's cash balances, *ceteris paribus*. Second, the increase in production causes the real return on capital to rise. Both of these effects allow the family to purchase more consumption and investment goods. The induced change in c_t^f then alters the punishment associated with being detected shirking through its effect on $\frac{c_t^f}{c_t^s}$, since:

32. These responses are common in the literature and have been supported by evidence in Christiano, Eichenbaum, and Vigfusson (2002). However, papers such as Basu, Fernald, and Kimball (1999) and Galí (1999) have suggested that technology improvements may, in fact, be contractionary in the short run and expansionary only in the long run.

Figure 3
The efficiency wage model's
responses to a positive technology shock



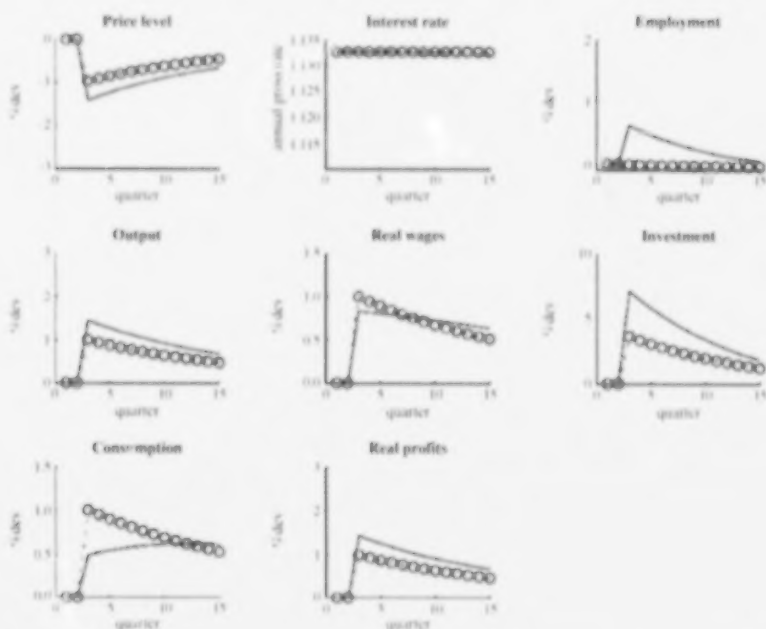
Notes: Partial income insurance, $v = 1.0$: $-\circ-\circ-$
 Partial income insurance, $v = 0.8$: $-\square-\square-$
 Full income insurance, $v = 1.0$: $\bullet-\bullet-\bullet$
 Full income insurance, $v = 0.8$: $\blacksquare-\blacksquare-\blacksquare$
 %dev = percent deviation from steady state.

$$\frac{c_t}{c_t^s} = \frac{w_t f - F_t + c_t^f}{s w_t f - F_t + c_t^f}.$$

In addition to the change in c_t^f caused by the change in output, a positive technology shock also increases the expected future return on capital since the shock is persistent. This induces the family to increase their investment in capital goods, thereby dampening the effects of the increase in $r_t K_t$ and the decrease in P_t on c_t^f . However, the results suggest that c_t^f increases in response to a technology shock.

Firms respond to the rise in the level of family consumption purchased by increasing wages to dissuade workers from shirking. This, in turn, increases

Figure 4
The standard limited-participation model's responses to a positive technology shock



Notes: Limited participation, $v = 1.0$: —
 Limited participation, $v = 0.8$: - - -
 %dev = percent deviation from steady state.

the marginal cost of labour. In practice, however, the increase in the marginal product of labour is larger than the increase in the marginal cost of labour. Therefore, the models predict that, following a positive technology shock, output, employment, consumption, investment, and wages increase, while prices decrease. Finally, the model also predicts that the interest rate is initially unaffected, because the money stock is unaffected by the shock and the level of deposits is initially fixed because of the limited-participation assumption.

2.3 Monetary policy shocks

Figures 5 and 6 display the impulse-response functions of the efficiency wage and limited-participation models for an expansionary monetary policy shock. Despite the fact that both models are consistent with the qualitative

results outlined in Christiano, Eichenbaum, and Evans (1997) and Sims and Zha (1996), they differ with respect to their quantitative responses. Figure 5 demonstrates that the magnitude of the efficiency wage model's responses depends on the form of the intrafamily transfer, and a comparison of Figures 5 and 6 highlights the differences between the responses in the efficiency wage model and the standard limited-participation model. The partial income insurance case produces the least inflation, the smallest real-wage response, and the largest output, consumption, employment, and investment responses, compared with the full income insurance case and the standard limited-participation model. Moreover, these figures show that increasing the costs of capital adjustment lessens the increase in employment, output, and investment in response to a positive monetary shock, and increases the real-wage response.

In the monetary efficiency wage models, an unexpected increase in the stock of money initially has two effects. First, financial intermediaries have more funds to lend to firms. In response, the financial intermediaries lower the interest rate on loans to induce firms to borrow the excess funds. Everything else held equal, this decrease in the interest rate lowers the firms' marginal cost of labour. Since profit-maximizing firms choose employment to equate the marginal product of labour to the marginal cost of labour, the decrease in the marginal cost of labour causes firms to expand the size of their labour force. In turn, this increases the economy's output and the return on capital.

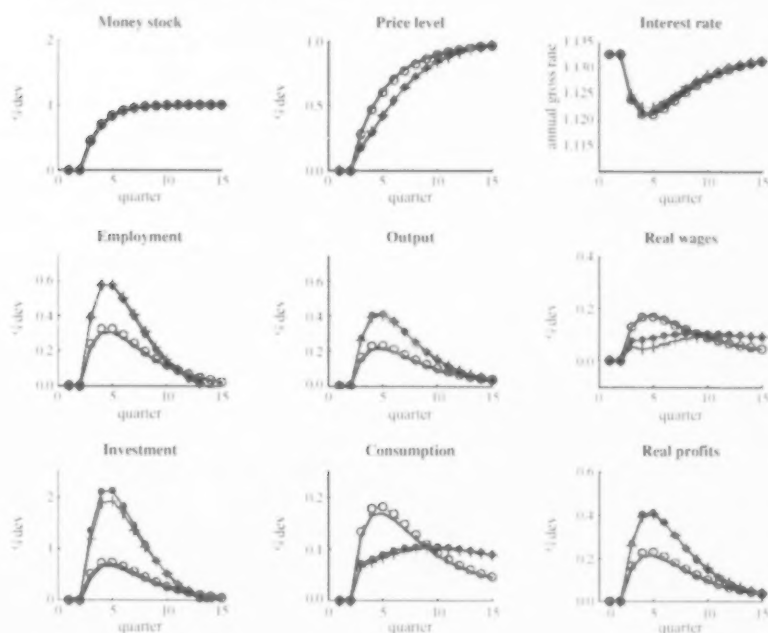
Second, the increase in the stock of money puts upward pressure on prices, if the response of output is small. This is seen clearly from the goods market clearing condition where:

$$P_t Y_t = \frac{1}{\left(1 - \frac{\alpha}{\mu}\right)} (M_t + X_t).$$

It follows that an increase in the price level causes the family's purchasing power to decrease since their cash balances can now buy less. Moreover, this decrease in purchasing power affects both family consumption and investment.

The effect of an expansionary monetary policy shock on c_t^f is generally uncertain. For example, if families choose to reduce capital investment enough in response to the shock, c_t^f may increase overall, despite the decrease in purchasing power. If this occurs, the punishment associated with being detected shirking decreases, and firms must raise wages in order to maintain the same effort level in equilibrium. The increase in wages raises the marginal cost of labour for a given interest rate and causes firms to

Figure 5
The efficiency wage model's responses
to a positive monetary policy shock



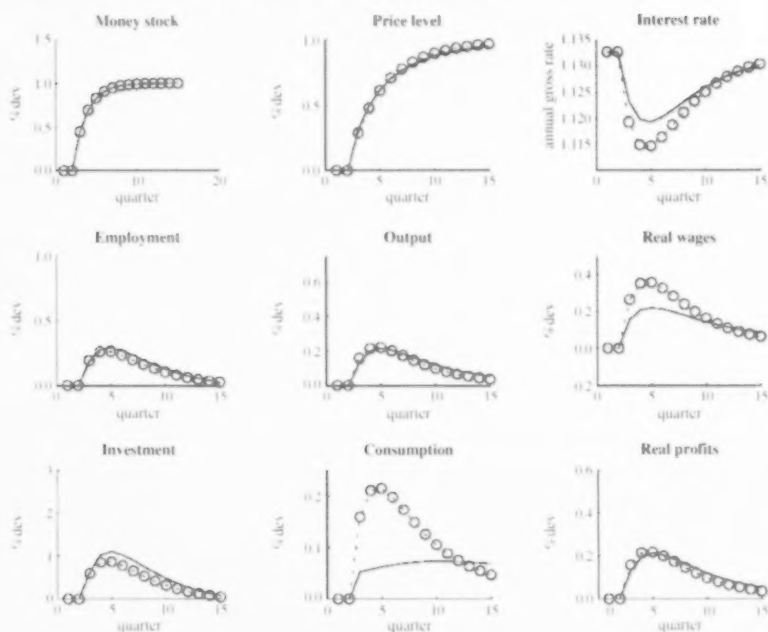
Notes: Partial income insurance, $v = 1.0$: $-\circ-\circ-$
 Partial income insurance, $v = 0.8$: $-\bullet-\bullet-$
 Full income insurance, $v = 1.0$: $-\bullet-\bullet-$
 Full income insurance, $v = 0.8$: $-\bullet-\bullet-$
 % dev = percent deviation from steady state.

decrease the number of workers hired, all else being equal. Depending on the magnitude of the increase in c_t^f , the real wage could increase enough to offset the effect of the decreasing interest rates on the marginal cost of labour. However, in the estimated versions of the model, it is clear that employment rises following the positive monetary policy shock.

2.4 The J-test

Tables 4 to 6 present the Wald tests that formally explore the hypothesis that the second moments from the estimated models are the same in population as the second moments estimated from the data. The results clearly indicate that the efficiency wage model is better able to produce low real-wage

Figure 6
The standard limited-participation model's
responses to a positive monetary policy shock



Notes: Limited participation, $\nu = 1.0$: —
 Partial income insurance, $\nu = 0.8$: - - -
 % dev. = percent deviation from steady state.

variation and high employment variation. The lowest real-wage variation and highest employment variation are obtained from the efficiency wage model with partial income insurance. Increasing the cost of adjustment on capital decreases the employment variation and increases the wage variation in both models. The results also show that the standard limited-participation model also needs a higher adjustment cost on capital to capture the second moments of interest. Both models have the best fit for $\nu = 0.8$. However, unlike a standard model, the efficiency wage model does not require a high markup or a high labour-supply elasticity when $\nu = 0.8$.

Conclusions

This paper develops a monetary business cycle model where: (i) individuals make nominal savings decisions before observing the period's shocks;

Table 4
Second moments

Moment	$v = 1.0$					
	$\frac{\sigma_c}{\sigma_y}$	$\frac{\sigma_i}{\sigma_y}$	$\frac{\sigma_g}{\sigma_y}$	σ_n	σ_w	σ_v
Canadian data	0.8674 (0.0501)	2.9587 (0.3916)	0.9445 (0.1265)	0.0085 (0.0011)	0.0110 (0.0012)	0.0135 (0.0015)
Efficiency wage	0.2687 (0.0297)	4.6308 (0.9045)	0.6752 (0.1119)	0.0286 (0.0061)	0.0064 (0.0011)	0.0263 (0.0041)
<i>p</i> -value	0.0000	0.0919	0.0921	0.0016	0.0074	0.0040
Efficiency wage	0.2830 (0.0300)	4.9895 (0.3247)	0.6945 (0.0689)	0.0273 (0.0036)	0.0072 (0.0006)	0.0255 (0.0024)
Full income insurance	0.0000	0.0000	0.0571	0.0000	0.0021	0.0000
<i>p</i> -value	0.0000	0.0000	0.0571	0.0000	0.0021	0.0000
Standard limited participation	0.3885 (0.0448)	5.0222 (0.8796)	1.0895 (0.1031)	0.0126 (0.0021)	0.0113 (0.0017)	0.0163 (0.0014)
<i>p</i> -value	0.0000	0.0328	0.3114	0.1011	0.8830	0.1767

Table 5
Second moments

Moment	$v = 0.9$					
	$\frac{\sigma_c}{\sigma_y}$	$\frac{\sigma_i}{\sigma_y}$	$\frac{\sigma_g}{\sigma_y}$	σ_n	σ_w	σ_v
Canadian data	0.8674 (0.0501)	2.9587 (0.3916)	0.9445 (0.1265)	0.0085 (0.0011)	0.0110 (0.0012)	0.0135 (0.0015)
Efficiency wage	0.5834 (0.0602)	3.6206 (0.4973)	1.0145 (0.1038)	0.0165 (0.0029)	0.0097 (0.0016)	0.0175 (0.0016)
Partial income insurance	0.0009	0.3000	0.6309	0.0141	0.5319	0.0722
<i>p</i> -value	0.0007	3.7061	1.0438	0.0158	0.0102	0.0170
Efficiency wage	0.6007 (0.0350)	3.7061 (0.3045)	1.0438 (0.0900)	0.0158 (0.0022)	0.0102 (0.0010)	0.0170 (0.0012)
Full income insurance	0.0000	0.0771	0.4520	0.0045	0.5437	0.0895
<i>p</i> -value	0.0000	0.0771	0.4520	0.0045	0.5437	0.0895
Standard limited participation	0.6654 (0.0327)	3.6281 (0.2442)	1.3301 (0.1088)	0.0091 (0.0012)	0.0120 (0.0011)	0.0133 (0.0009)
<i>p</i> -value	0.0012	0.1434	0.0055	0.7702	0.5518	0.9221

Table 6
Second moments

Moment	$v = 0.8$					
	$\frac{\sigma_e}{\sigma_y}$	$\frac{\sigma_i}{\sigma_y}$	$\frac{\sigma_{\varepsilon}}{\sigma_y}$	σ_{π}	σ_{π}	σ_v
Canadian data	0.8674 (0.0501)	2.9587 (0.3916)	0.9445 (0.1265)	0.0085 (0.0011)	0.0110 (0.0012)	0.0135 (0.0015)
Efficiency wage	0.7898 (0.0670)	2.9948 (0.3166)	1.2046 (0.1199)	0.0135 (0.0025)	0.0113 (0.0016)	0.0145 (0.0012)
Partial income insurance	0.3851	0.9426	0.0951	0.0807	0.8935	0.5405
<i>p</i> -value						
Efficiency wage	0.7931 (0.0520)	2.9754 (0.2546)	1.2393 (0.1075)	0.0127 (0.0022)	0.0114 (0.0013)	0.0143 (0.0010)
Full income insurance	0.2840	0.9661	0.0470	0.0916	0.8134	0.6751
<i>p</i> -value						
Standard limited	0.9973 (0.1094)	3.7253 (0.5692)	1.3823 (0.1405)	0.0103 (0.0017)	0.0164 (0.0031)	0.0128 (0.0011)
participation	0.3111	0.2786	0.0076	0.4027	0.1170	0.7220
<i>p</i> -value						

(ii) a worker's effort level is only imperfectly observed by firms; and (iii) detected shirkers forgo an increase in their compensation. The first two assumptions are common in limited-participation models and shirking efficiency wage models, respectively. However, the assumption that detected shirkers forgo a raise or a bonus is a departure from the assumption made in the standard shirking efficiency wage models. This difference in the punishment is largely responsible for the model's ability to produce large employment variation and small real-wage variation without relying on a high labour-supply elasticity or a high markup. As a result, this model is more consistent with microeconomic evidence about the size of markups and the value of the labour-supply elasticity of individuals.

The paper's findings also illustrate that the quantitative results are sensitive to the type of income insurance provided to the unemployed. In particular, it is found that the efficiency wage model with partial income insurance tends to overshoot the employment variation seen in the data, and that the model's performance is improved by small adjustment costs on capital. Since the model is able to generate very large employment fluctuations, adjustment costs on labour may further improve the model's performance.

The model's impulse responses to monetary and fiscal policy shocks as well as technology shocks are examined. Consistent with the existing empirical evidence, the monetary efficiency wage model predicts that, in response to a positive monetary policy shock, real wages, output, employment, investment, and prices increase, while the gross interest rate decreases.

In response to a positive fiscal policy shock, employment, output, and investment increase, the gross interest rate weakly increases, while real wages and consumption decrease. Although these responses are consistent with the empirical findings in Ramey and Shapiro (1998) and Edelberg, Eichenbaum, and Fisher (1998), the model also predicts that the price level decreases in response to the shock, which is inconsistent with the evidence.

Finally, the model's responses to a positive technology shock are examined. The responses to the technology shock are qualitatively consistent with the predictions of the standard limited-participation model. In particular, the monetary efficiency wage model predicts that in response to an exogenous increase in the level of technology, real wages, employment, output, investment, and the capital rental rate increase, and the price level decreases. Although there is evidence that positive technology shocks are eventually expansionary, the model does not replicate the findings in papers such as Basu, Fernald, and Kimball (1999), that an increase in the level of technology may initially be contractionary.

By examining the implied impulse responses to fiscal policy, technology, and monetary policy shocks for the standard limited-participation model, and comparing them to the corresponding figures for the efficiency wage model, it is evident that the models produce different quantitative results. For example, the efficiency wage model produces larger increases in employment, output, and investment in response to all of the shocks considered. However, the responses of wages, prices, and consumption depend on the type of shock. In particular, the estimated efficiency wage model predicts larger movements in real wages and smaller movements in consumption in response to a fiscal policy shock, while technology and monetary policy shocks predicted smaller wage movements with larger movements in consumption. In the efficiency wage model, prices respond less to a monetary policy shock and respond more to fiscal policy and technology shocks, in comparison with the standard limited-participation model.

The results support the hypothesis that introducing efficiency wage considerations can help reproduce the real-wage variation and high employment variation seen in the data without relying on the presence of a high labour-supply elasticity. Furthermore, the model is consistent with empirical evidence on how economies respond to fiscal and monetary policy shocks. Future work should concentrate on: (i) improving the predicted response to a technology shock and the price responses to a fiscal policy shock; and (ii) eliminating the need for adjustment costs on the flow of funds to the goods.

Appendix 1

The Data

To estimate the models, a data set similar to the one used in Burnside and Eichenbaum (1996a), was built using quarterly time series from the OECD quarterly national accounts, Statistics Canada, the OECD International sectoral database, and historical estimates of M2 for the period 1961–97. The official capital stock was obtained from the International sectoral database. Using these statistics, the capital stock, K_t , includes the producer structures, equipment, and private residential capital, plus the government non-residential capital.

Private consumption, C_t , investment, I_t , and government expenditures, G_t , are defined as in the OECD national accounts. The GDP deflator is for base year 1992 and is used to convert data variables between their nominal and real levels. The interest rate was measured using data available from Statistics Canada on the prime lending rate on loans. Finally, the monetary aggregate represented in the model was measured by M2. The series for M2 was obtained by combining the numbers available from Statistics Canada with earlier estimates from Metcalf, Redish, and Shearer (1998).

Two additional variables were needed to estimate the model: wages and employment/hours. The employment data were created using Statistics Canada's unemployment rate, while the wage series was defined as total compensation reported in the OECD quarterly national accounts. Although the employment rate is directly used in the efficiency wage models, the standard limited-participation model is estimated using the number of hours worked normalized by the number of leisure/labour hours available to individuals over the period.

To keep the data set as consistent as possible across the different models, all data were converted to per-capita terms by dividing by the size of the labour force, obtained from Statistics Canada. This normalization then allowed for a computation of an implied hourly employment series by taking a stand on the number of hours an individual worked per week. For this model, individuals were assumed to work 40 hours per week. The series for quarterly hours worked was then created using the formula $\frac{40 \times 52}{4} (1 - \mu_t)$ where μ_t is the unemployment rate. This series was used in the divisible and indivisible labour models after it was normalized by the number of leisure/labour hours available to individuals during the quarters.

Appendix 2

The Estimated Equations

The monetary efficiency wage model's parameters,

$$\left\{ \frac{d}{\theta}, \delta, \tau_x, \mu_x, \rho_x, \sigma_x, \ln(A), \rho_A, \sigma_A, A_y, \ln(\gamma), \alpha, \ln\left(\frac{g}{y}\right), \mu_s, \mu, \rho_s, \sigma_s \right\}.$$

are simultaneously estimated from the following exactly identifying restrictions:

$$E\left(\frac{(1-\alpha)}{\mu} - \frac{R_t w_t N_t}{Y_t}\right) = 0$$

$$E(\ln(A_t) - \ln A - \rho_A \ln(A_{t-1})) = 0$$

$$E((\ln(A_t) - \ln A - \rho_A \ln(A_{t-1})) \times \ln(A_{t-1})) = 0$$

$$E((\ln(A_t) - \ln A - \rho_A \ln(A_{t-1}))^2 - \sigma_A^2) = 0$$

$$E(\ln(Y_t) - A_y - t \times \ln(\gamma)) = 0$$

$$E\left((\ln(Y_t) - A_y - t \times \ln(\gamma)) \times \frac{t}{149}\right) = 0$$

$$E\left(t - \delta^{\left(1 - \frac{1}{v}\right)} (K_{t+1}^v - (1 - \delta)K_t^v)^{\frac{1}{v}}\right) = 0$$

$$E\left(\begin{array}{l} muc_t \delta^{\left(1 - \frac{1}{v}\right)} (K_{t+1}^v - (1 - \delta)K_t^v)^{\frac{1}{v}-1} K_{t+1}^{v-1} \\ - \beta muc_{t+1} \left(\frac{\alpha Y_{t+1}}{\mu K_{t+1}} + (1 - \delta) \delta^{\left(1 - \frac{1}{v}\right)} (K_{t+2}^v - (1 - \delta)K_{t+1}^v)^{\frac{1}{v}-1} K_{t+1}^{v-1} \right) \end{array}\right) = 0$$

$$E(N_t - N^{ss}) = 0$$

$$E\left(\ln(G_t) - \ln(Y_t) - \ln\left(\frac{g}{y}\right)\right) = 0$$

$$E\left(\ln\left(\frac{G_t}{Y_t}\right) - \mu_g - t \times \tau_g\right) = 0$$

$$E\left(\left(\ln\left(\frac{G_t}{Y_t}\right) - \mu_g - t \times \tau_g\right) \times \frac{t}{149}\right) = 0$$

$$E\left(\left((1 - \rho_g L) \times \left(\ln\left(\frac{G_t}{Y_t}\right) - \mu_g - t \times \tau_g\right)\right) \times \left(\ln\left(\frac{G_{t-1}}{Y_{t-1}}\right) - \mu_g - \tau_g \times (t-1)\right)\right) = 0$$

$$E\left(\left((1 - \rho_g L) \times \left(\ln\left(\frac{G_t}{Y_t}\right) - \mu_g - t \times \tau_g\right)\right)^2 - \sigma_g^2\right) = 0$$

$$E(x_t - (1 - \rho_x)\mu_x - \rho_x x_{t-1}) = 0$$

$$E((x_t - (1 - \rho_x)\mu_x - \rho_x x_{t-1}) \times x_{t-1}) = 0$$

$$E((x_t - (1 - \rho_x)\mu_x - \rho_x x_{t-1})^2 - \sigma_x) = 0,$$

where muc_t is the marginal utility of c_t^f for the family. The parameters of the standard limited-participation model are estimated using the same identification scheme with this model's marginal utility of consumption data, muc_t , hourly employment data, N_t , and its expression for the steady-state value of employment, N^{ss} . In this case, the equation equating the employment hours and the steady-state value of employment hours identifies the parameter value θ , instead of the variable $\frac{d}{\theta}$, as in the efficiency wage model.

The identifying restrictions for the J -test are described below.

To test the models' predictions for $\left\{ \frac{\sigma_c}{\sigma_y}, \frac{\sigma_i}{\sigma_y}, \frac{\sigma_g}{\sigma_y}, \sigma_n, \sigma_n, \sigma_y \right\}$, the HP-filtered data, $\left\{ c_t^{hp}, i_t^{hp}, g_t^{hp}, y_t^{hp}, n_t^{hp}, w_t^{hp} \right\}$, are used along with the following equations:¹

$$E\left(\left(y_t^{hp}\right)^2 \left(\frac{\sigma_c}{\sigma_y}\right)^2 - \left(c_t^{hp}\right)^2\right) = 0$$

$$E\left(\left(y_t^{hp}\right)^2 \left(\frac{\sigma_i}{\sigma_y}\right)^2 - \left(i_t^{hp}\right)^2\right) = 0$$

$$E\left(\left(y_t^{hp}\right)^2 \left(\frac{\sigma_g}{\sigma_y}\right)^2 - \left(g_t^{hp}\right)^2\right) = 0$$

$$E\left(\left(n_t^{hp}\right)^2 - (\sigma_n)^2\right) = 0$$

$$E\left(\left(y_t^{hp}\right)^2 - (\sigma_y)^2\right) = 0$$

$$E\left(\left(w_t^{hp}\right)^2 - (\sigma_w)^2\right) = 0.$$

These moments were simultaneously estimated with the models' parameters.

1. $\lambda = 1,600$ when the data were filtered.

Appendix 3

The Standard Limited-Participation Model

The standard limited-participation model with divisible labour is based on Christiano, Eichenbaum, and Evans (1997) and has the same six sectors as the efficiency wage model presented in the paper. The problems facing the monetary authority, the final good firms, and the government are identical to those described in the efficiency wage model. However, the individual's problem, the intermediate goods firms' problems, and the loan market clearing condition differ slightly due to the observability of effort and the divisibility of labour.

The individual's problem in the standard limited-participation model is:

$$\max_{\{c_t, K_{t+1}, M_{t+1}, D_t\}_{t=0}^{\infty}} E_0 \left[\sum_{t=0}^{\infty} \beta^t \left\{ \ln(C_t) + \theta \ln(1 - N_t) - \theta \ln(1 + H(Q_t, Q_{t-1})) \right\} \right],$$

subject to $P_t C_t \leq M_t - D_t - P_t Tax_t + P_t r_t K_t - P_t I_t + W_t N_t$, and

$$M_{t+1} = M_t - D_t - P_t C_t - P_t Tax_t + P_t r_t K_t + W_t N_t - P_t I_t + R_t(D_t + X_t) + PR_t,$$

$$\text{where } H(Q_t, Q_{t-1}) = a_0 \left[\exp \left[a_1 \left(\frac{Q_t}{Q_{t-1}} - 1 - x \right) \right] + \exp \left[-a_1 \left(\frac{Q_t}{Q_{t-1}} - 1 - x \right) \right] - 2 \right],$$

$Q_t = M_t - D_t$, C_t is the individual's consumption, N_t is the percentage of time the individual spends working for firms, r_t is the real return on capital, K_t is the amount of capital available during time t , P_t is the price level, M_t is the beginning of period stock of money, I_t is investment, W_t is the nominal wage, D_t is the amount of nominal deposits chosen in advance of the shocks, R_t is the nominal interest rate, Tax_t is the amount of taxes owed at time period t , and $R_t X_t$ and PR_t are the profits received from financial intermediaries and intermediate goods firms, respectively.

In the limited-participation model, firms do not require effort from workers for production. The resulting intermediate goods firm's period t problem in this case is:

$$\max_{\{P_{it}, N_{it}, K_{it}\}} \left\{ P_{it} (A_t K_{it}^{\alpha} (N_{it})^{1-\alpha}) - R_t P_{it} W_{it} N_{it} - P_t r_t K_{it} \right\}$$

subject to the period-by-period demand functions:

$$P_t^{1-\mu} \left(A_t K_t^\alpha (N_t)^{1-\alpha} \right) - P_t^{1-\mu} Y_t = 0.$$

Finally, using the fact that the intermediate goods firms borrow their wage bill from the financial intermediaries, the loan market clearing condition becomes:

$$\int_0^1 W_{it} N_{it} di = D_t + X_t,$$

where $W_{it} N_{it}$ is firm i 's wage bill in period t , D_t are the deposits, and X_t is the amount of the monetary injection.

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Discussion

Scott Hendry

I very much enjoyed reading the paper and believe it makes useful contributions to the literature. I have no major criticisms; consequently, my comments will address details of the model and the results. I will also make a few recommendations for extensions.

The Alexopoulos paper embeds an efficiency wage model in an otherwise relatively standard limited-participation model. The goal is to show that such a model does not require the usual unrealistic assumptions of high labour supply elasticity or high price markups in order to reproduce the stylized fact from U.S. data that employment is highly variable relative to real wages. Other work in the literature has proposed indivisible labour, search frictions, or home production as frameworks for generating large employment variations and much smaller real-wage fluctuations. The proposed efficiency wage model is standard, except that workers are not fired when they are discovered shirking. Instead, firms simply do not pay workers their quarterly bonus at the end of the period. This small change to the model greatly improves its ability to replicate the relative volatilities of employment and real wages. The degree of income insurance for unemployed workers also plays an important role in the model.

The paper estimates many of the model's parameters, using a Generalized Method of Moments procedure, which is still relatively uncommon in the dynamic general-equilibrium (DGE) literature. A number of important parameters, such as the adjustment-cost parameters and some efficiency wage parameters, are still calibrated, and an attempt should be made to estimate them in future work.

Another contribution of the paper is the addition of a model of equilibrium unemployment into a standard DGE model. Although a couple of papers

have completed similar exercises, particularly with search models of unemployment (see Andolfatto 1996), it is quite surprising that models with unemployment, such as this one, are still not standard for important macroeconomic analysis. Consequently, this model is an important step forward, especially for central bankers concerned with the behaviour of the Phillips curve.

The paper argues that the model with partial income insurance better replicates the desired relative volatilities of employment and real wages. One could argue, however, that the full-insurance model better replicates the data because it gets closer to the relative size of the two variances and much closer to the absolute variance for employment, while giving up only a little extra in terms of real-wage variance. The full-insurance model also seems better because it gets closer to the data for the relative volatilities of employment and output. In addition, the real wage, under partial insurance and using U.S. data,¹ has a countercyclical flavour in the response to a monetary policy shock, while the full-insurance case has a procyclical response as in the data. Given these results, one could argue that the full-insurance model better replicates the data. However, we all know that the real world is not characterized by full-insurance schemes. I would be interested in any explanation of why the full-insurance model seems to do so well. Also, given that the model is estimated, it would be good to simply let the data speak and estimate the degree of income insurance. I understand that other second moments not shown in the paper do lead to a preference for the partial-insurance model. It is still surprising, however, that the partial-insurance model does not more obviously outperform the full-insurance case.

The paper focuses on replicating employment and real-wage variability. I would also be interested in the model's ability to replicate the dynamics of unemployment. It is quite possible that, given the model has no labour supply variation so that employment changes are simply the inverse of unemployment changes, the model replicates employment well but unemployment poorly. I understand from discussions with the author that unemployment dynamics are reasonably well approximated, but I would like to see evidence in the paper.

Similarly, it would be useful to allow for variation in both the intensive and extensive labour margins. Granted, the data imply that most variation is in employment, as in the model, but there is also some variation in hours worked by each employee. Since the model is estimated, the data could be

1. As I understand it, this is not a robust feature of the model, but it does occur in some specifications.

used to decide how much variation to attribute to hours, employment, the labour supply, and possibly, effort.

Impulse responses and the relative volatilities of employment and wages are the main criteria used. I would also like to see how well the model tracked the actual movements of these series over time. This could be done by simply looking at a graph of actual and fitted data. When does the model fit well? When does it fit poorly? The estimated shock series could also be examined to determine whether they conform with our expectations of when the economy was hit by large fiscal, technology, and monetary policy shocks. A more structured comparison would be to estimate some cross-correlation coefficients along with the variances. For instance, the correlation of employment with output and real wages would be most interesting. Since the real wage is countercyclical for some specifications of the model (using U.S. data) following a monetary policy shock, the model may not replicate these correlations very well.

Another metric for evaluating the models would be to do a variance decomposition of the data to determine the sources of most of the volatility in output, inflation, and employment. There are numerous other studies with which these results could be compared in terms of output and inflation. Not too many have done this for employment, however. Finally, stability tests of the parameters would lend credence to the estimates as well as to the model's policy predictions.

I was intrigued by the model's hump-shaped real-impulse responses following a monetary policy shock. In contrast, there was no hump-shaped response for either fiscal or technology shocks. It is interesting that there is more real rigidity or delayed response for a nominal shock than for a real shock. I believe that this delayed real response comes from the portfolio-adjustment cost and not from the labour market frictions. That is why this hump shape is more evident following a monetary shock (when this cost matters most) than it is for the other shocks. This interpretation is supported by the fact that the basic limited-participation model also generates the same hump shape although with a smaller peak. The efficiency wage frictions may generate unemployment, but they do not add much in the way of persistence to either employment or real wages.

This reasoning carries over to my next point—that it would be very interesting to add a flavour of labour market search on top of the efficiency wages. Search frictions could also be used as a way of avoiding the necessity of assuming high labour supply elasticities in DGE models. With both types of frictions in the same model, one could estimate the relevant parameters and determine the relative contributions of search and efficiency wages to output, employment, and real-wage dynamics.

In the same vein, one could estimate more of the efficiency wage parameters in the model to better judge the model's applicability. As I mentioned earlier, the size of the bonus, s , should be estimated instead of calibrated. It would also be an improvement if this differed from the degree of insurance coverage that was also estimated.

In another efficiency wage model, Burnside, Eichenbaum, and Fisher (2000) found that variable marginal taxes (instead of lump sum taxes) made it difficult to match the dynamics of employment following a fiscal policy shock. In particular, their model generated a result that hours worked initially rose following a positive fiscal shock but quickly reversed and reached its trough at approximately the same time that the fiscal shock reached its peak. There is no evidence in the data that hours worked declines in this manner. The authors needed to fix their marginal tax rates and vary lump sum taxes to pay for the fiscal shock, much as the Alexopoulos paper does, in order to get hours worked to respond only positively. It would be worth investigating how the current model performs with marginal taxes on wages and consumption instead of lump-sum taxes.

The paper could be expanded to better explain its support for the efficiency wage explanation over the indivisible labour, search friction, or home production explanations of the volatilities of employment and real wages. It is not clear why we should believe this explanation more than the others. I therefore believe it would be worthwhile to embed a couple of these factors within the same model and then estimate it. A discussion of the overlap and differences between these explanations or models would also be useful.

One final modification of the model would be to assume that monetary policy follows a Taylor-like interest rate rule instead of an AR(1) in money growth. This would obviously be a more accurate representation of monetary policy and, in numerous studies, it has been shown to substantially affect the model's dynamics.

I would like to emphasize that this paper tackles an interesting question in an innovative manner. My enthusiasm for the work is reflected in my desire to see the results of my suggested extensions.

References

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General Discussion*

In her response to Scott Hendry, Michelle Alexopoulos explained that many of his concerns had already been dealt with in a sensitivity analysis that had not been discussed in the paper. Addressing other issues raised by Hendry, Alexopoulos said that she prefers the partial over the full income insurance model, because it overstates the variation in unemployment. This is beneficial, since it captures several dynamics not accounted for in her model, such as adjustment costs in employment. She also commented that using indivisible labour would not change her results.

Referring to the author's model, Allen Head noted that the ability to punish workers strengthens during a boom, but this ability weakens in a search model. He then asked what is observed in actual micro labour market data. Alexopoulos confirmed that the data support her efficiency wage model.

Nicholas Rowe acknowledged that the model accounts for what is observed in short-run time series data. He added, however, that in long-run time series data and cross-country data, there is very little variation in the natural rates of employment, and the majority of the variation is observed in wages. Rowe asked whether her efficiency wage model accounts for this long-run phenomenon. Alexopoulos explained that the family structure in her model allows for growth and, consequently, the long-run predictions result in a natural rate of stable employment. Martin Eichenbaum joined the discussion by adding that since Alexopoulos is using a balanced-growth model, the wage rate is growing in the steady state and employment is not. He noted that in this model, monetary policy is represented by a Taylor rule and not by assuming a money-growth policy.

* Prepared by Francisco Barillas and Hussein Allidina.

Since the often-favoured sticky-price model provides better long-term predictions, Frank Smets questioned Alexopoulos's choice of the efficiency wage model. By changing the timing slightly, Alexopoulos explained, her model could obtain optimal nominal-wage rigidity, which would provide the same results as those derived using the other model.

James Nason wondered whether Alexopoulos had considered the case where the constant elasticity of substitution moved below one and noted that the cost of adjustment might appear different. He also asked whether she had contemplated incorporating habit formation into her model. Alexopoulos had not previously considered these suggestions and made note of them.

How Certain Are We About the Role of Uncertainty in the Labour Contract Duration Decision? Evidence for Canada and Implications

*Robert Fay and Sébastien Lavoie**

Introduction

One of the stylized facts of Canadian labour markets in the 1990s and into the new millennium is a lengthening in labour contract duration. Various authors have analyzed the underlying factors influencing the duration of labour contracts in Canada, but they have typically covered only periods up to the late 1980s or early 1990s. A particular area of interest to the Bank of Canada is the role played by inflation uncertainty. Since the adoption of an inflation target by the Bank of Canada in 1991, Longworth (2002) documents that based on a variety of measures, both the level and variability of inflation have fallen. Moreover, a lengthening in contract duration has been cited as an indicator of increased monetary policy credibility by many authors (e.g., Amano, Coletti, and Macklem 1999; Jenkins and O'Reilly 2001; and Longworth 2002). With about 10 years under the new inflation regime, it is therefore an opportune time to re-examine the impact of inflation uncertainty on the duration of labour contracts. The limited empirical evidence for Canada suggests a negative relationship, i.e., that

* We would like to thank René Lalonde and Danny Leung for their helpful assistance on the various econometric methodologies used in this paper. Allan Crawford, Tiff Macklem, Gerald Stuber, and Francis Vitek also provided useful comments. In addition, we would like to thank participants at a workshop held in the Research Department at the Bank of Canada, as well as those at this conference, and our discussant, John Knowles, for helpful comments. Annie De Champlain and Kara Flanagan provided excellent technical assistance. Of course, any errors in the paper are ours alone.

greater inflation uncertainty tends to reduce contract length. This is also a finding from the U.S. literature in the area. In addition, with inflation low and stable, bargaining units (BUs)—unions and firms—may have become relatively more concerned about changes in the real economy (for example, whether a recession is likely) and take this into account. Thus, another goal of this paper is to extend the literature in the Canadian context by examining the role of real uncertainty. Since there are several ways that uncertainty may be measured, this paper discusses three methods: statistical-based, those derived from surveys, and regression-based measures. The paper also examines the robustness of the results against various specifications of the uncertainty measures.

Although several uncertainty measures are created and discussed, the empirical analysis focuses on two regression-based methodologies: uncertainty measures derived from either the estimation of autoregressive conditional heteroscedasticity (ARCH) models or a structural vector autoregression (SVAR). The results suggest that inflation uncertainty is significantly related to contract duration, and this finding holds for both methodologies. There is no evidence of a significant link between real uncertainty and contract duration.

The paper begins with an overview of the theoretical link between uncertainty and contract duration. It then discusses the various uncertainty measures that have been used in studies on the determinants of labour contract duration. This is followed by a critique of their relative merits. The paper then provides a summary of the previous empirical research in the area, a description of the estimation techniques used in the analysis, and a presentation of the estimation results. The final section concludes and provides some implications of the results. The appendixes provide additional information on the estimation methodology and results.

1 Theoretical Work

The theoretical research on the duration of labour contracts began with a paper by Gray (1978), who developed a model to determine the optimal labour contract length and the degree of indexation. She shows that, on the one hand, longer contracts allow firms and workers to amortize the costs of negotiation over a greater time period. On the other, shorter contracts minimize the deviations of wages, output, and employment from their desired values because of unforeseen shocks. Thus, the optimal contract duration balances the costs of contracting with potential deviations of variables from their desired levels. Gray argues that for a given degree of indexing, contract length is a decreasing function of uncertainty (no matter what the source) and an increasing function of the costs of contracting.

Canzoneri (1980) came to the same conclusion as Gray by developing a policy evaluation model. In his model, if monetary policy reduces uncertainty in the economy, then contract length becomes longer, and employment, output, and prices all have longer cyclical lags. Indeed, he notes on page 254 of his paper that the result would be a "more inertia ridden cyclical structure with a dampened amplitude."

Danziger (1988) argues that it is important to distinguish between nominal and real uncertainty. In his model, an increase in uncertainty due to changes in real factors such as oil-price shocks leads to longer contract duration, and not shorter, as suggested by Gray and Canzoneri. Basically, workers seek to protect themselves partially or fully against the effects of real shocks by signing longer contracts, which act as a form of insurance. He refers to this as the efficient risk-sharing hypothesis. Moreover, Harris and Holmstrom (1987) suggest that in periods of high uncertainty, information-gathering costs may escalate rapidly, boosting negotiation costs and making longer-term contracts more likely. On the other hand, it is well known that when inflation is very high and variable, contracting ceases to exist. Clearly, disentangling these effects is an empirical question.

1.1 How to measure uncertainty

Uncertainty is unobserved and measures therefore have to be constructed. Our definition of inflation uncertainty is taken from Stuber (2001), who argues that it is the degree to which the future inflation rate is unknown in the sense of not being predictable, given past performance. The literature, however, does not have a well-defined measure of real uncertainty. We therefore use one similar to that for inflation, i.e., we assume that it is the uncertainty faced by economic agents in the sense that the rate of future real output growth is uncertain, given past performance.

Most empirical work has proxied uncertainty in three main ways, using statistical-based measures, those derived from surveys, and measures created through regression analysis. We discuss each method below.

1.1.1 Statistical measures

Statistical measures of inflation uncertainty are usually a simple filter of the data. Those used in various studies include a moving average of the standard deviation of core inflation¹ (Stuber 2001; Longworth 2002) and its coefficient of variation (Kanago 1998). As regards real uncertainty,

1. Core inflation is defined as the consumer price index (CPI) excluding the eight most volatile components and the effects of indirect taxes on the remaining items (see <http://www.bankofcanada.ca/en/press/background.pdf>).

statistical indicators can be developed similar to those for inflation, using a moving average of the standard deviation and of the coefficient of variation of real GDP (Table 1).

1.1.2 Survey-based measures

Survey-based measures have also been used in previous studies, namely the Livingston Survey in the United States (Vroman 1989). In Canada, roughly similar survey data are available from the Watson Wyatt (formerly KPMG) annual survey of medium-term inflation expectations of economists and portfolio managers.² One way to create a measure of inflation uncertainty is to calculate the difference between the upper and lower quartile forecasts among respondents (Stuber 2001; Longworth 2002). Similarly, real uncertainty measures can be derived from the Watson Wyatt Survey of real GDP medium-term forecasts.

1.1.3 Regression-based measures

There has been a considerable evolution in how to measure uncertainty using regression techniques. One of the earliest measures of inflation uncertainty was created by Christofides and Wilton (1983), and it has become the standard in empirical work on contract duration determinants. They ran a rolling regression of the CPI (quarterly growth at annual rates) (P_t) on a polynomial lag of degree 3 over an 11-quarter period. More formally, this can be stated as:

$$P_t = \alpha_0 + \alpha_1 P_{t-1} + \dots + \alpha_{11} P_{t-11} + dGST_t + e_t.$$

Note that we have included a dummy variable (GST_t) to control for price changes due to the introduction of the GST.³ Its introduction was well known by agents, and the impact on the price level should have been predictable. Christofides and Wilton found that a third-degree polynomial best fit the data:

$$\alpha_i = a_0 + a_1 i + a_2 i^2 + a_3 i^3.$$

Uncertainty for a specific period is obtained by the square root of the standard error of the estimate (SEE):

2. In particular, participants in the Watson Wyatt Survey are asked to provide their medium-term average forecasts for a set of variables, including real GDP and inflation, over a horizon of two to five years ahead (see Stuber 2001).

3. The specification of the dummy variable is as in Crawford and Kasumovich (1996).

Table 1

The pros and cons of the various uncertainty measures

Measure	Advantages	Disadvantages
Moving average of the standard deviation	relatively easy to calculate	- omits expectations - variability does not infer uncertainty
Moving average of the coefficient of variation	- relatively easy to calculate - relative measure of uncertainty	- omits expectations - variability does not infer uncertainty
Dispersion measures from surveys of expectations	ex ante measure based on forecasts	- annual survey - forecast horizon not necessarily in line with contract duration - does not take into account the uncertainty attached to each forecast - might be considered a proxy of disagreement
Rolling regression	- explicitly models the forecasting problem - widely used in the literature	choice of the lag structure is arbitrary in a polynomial lag equation
ARCH/GARCH models	- explicitly models the forecasting problem - uncertainty increases with forecast errors	- variance is assumed constant - relatively sophisticated form of uncertainty - measure of uncertainty is symmetric, although this assumption can be relaxed - potentially sensitive to model specification
Structural VAR model	uses a set of variables to identify nominal and real shocks instead of only a single variable	- relatively sophisticated form of uncertainty - potentially sensitive to model specification

$$SEE = \left(\left(\frac{1}{T-K} \right) \sum_{t=1}^n e_t^2 \right)^{\frac{1}{2}},$$

and the equation is then re-estimated for each quarter by adding an additional observation at the end of the sample and dropping the first observation at the beginning of the sample.⁴

Murphy (2000) used a similar technique to create a real uncertainty measure based on the U.S. unemployment rate. Adapting his method to the Canadian

4. For example, if a contract was signed in 1978Q4, then the square root of the SEE of the regression up to 1978Q3 is the estimate of inflation uncertainty. The regression was run using a rolling window, with the initial sample from 1960Q4 to 1978Q3.

context, it can be presented as a rolling regression of the quarterly unemployment rate:

$$\mu_t = \delta_0 + \sum_{i=1}^{11} \delta_i \mu_{t-i} + \sum_{i=1}^{11} \lambda_i \pi_{t-i} + v_t$$

where μ_t is the aggregate unemployment rate and π_t is the growth in inflation as measured by the CPI. The unemployment rate on the right-hand side of the equation is a polynomial lag of degree 3 over an 11-quarter period, while inflation is an 11-lag, second-degree polynomial. The CPI is included in the equation to control for changes in the unemployment rate due to nominal factors. The real uncertainty measure is the SEE from the regression.⁵

An alternative strategy to calculate inflation uncertainty is to use an ARCH-type model. We draw on work by Crawford and Kasumovich (1996), who created a measure of inflation uncertainty based on an autoregressive (AR) model with ARCH effects. The conditional mean function is defined as an AR(4) process:⁶

$$\pi_t = \beta_0 + \beta_1 \pi_{t-1} + \dots + \beta_4 \pi_{t-4} + dGST_t + u_t$$

where π_t is the year-over-year rate of change of the CPI, excluding food and energy and the effects of changes in indirect taxes, and GST_t is a dummy variable to control for price changes due to the introduction of the GST. The conditional variance of inflation is estimated as an ARCH(1) process:

$$h_t = \phi_0 + \phi_1 u_{t-1}^2 + \phi_2 \pi_{t-1}$$

where π_{t-1} is included in the variance specification to capture the link between uncertainty and the level of inflation. Inflation uncertainty is measured by the conditional variance of the one-quarter ahead forecast.

A univariate GARCH (generalized ARCH) model was used to create a real uncertainty proxy. Like inflation, real Canadian output growth ($ycan_t$)

5. The sample period is the same as for the inflation uncertainty measure constructed with the rolling regression. Wallace (2001) also created a measure of real uncertainty using similar techniques, though this latter measure was based on oil-price shocks. Specifically, the measure was the standard error from a one-period-ahead quarterly oil-price forecast, using an autoregressive model of the first difference of oil prices over the 1947–80 time period.

6. The model is estimated over the sample period 1962Q3 to 2001Q2.

exhibits significant conditional heteroscedasticity. Our conditional mean equation can be considered a reduced-form IS curve:

$$ycan_t = \gamma_0 + \gamma_1 ycan_{t-1} + \gamma_2 yus_t + \gamma_3 spread_{t-4} + \varepsilon_t,$$

where yus_t is real U.S. GDP growth and $spread_{t-4}$ is the Canadian term structure.⁷ The conditional variance of GDP growth is a GARCH (1,1) process:⁸

$$h_t = \Phi_0 + \Phi_1 \varepsilon_{t-1}^2 + \Phi_2 h_{t-1}.$$

The final regression method used to create uncertainty measures comes from Rich and Tracy (2000), who developed measures of uncertainty derived from the estimation of an SVAR based on a model developed by Gali (1992). They estimated a four-variable SVAR of real output growth, the change in the yield on the three-month Treasury bill, the ex post real return on the three-month Treasury bill, and the growth rate in the real money supply. The real aggregate shock was linked to real output growth and formed the real uncertainty measure. The remaining three variables comprised an aggregate demand shock and were used to create a nominal uncertainty measure.

The SVAR estimated in this paper is similar in spirit to that of Rich and Tracy. It contains five variables: real GDP, the inflation rate, the real short- and long-term interest rates, and the unemployment rate. From it, we create two aggregate uncertainty measures: a real uncertainty proxy using one permanent shock (real GDP) and one demand shock (unemployment rate), and a nominal uncertainty proxy, using the inflation and interest rate variables. This latter variable is therefore more broad than the inflation uncertainty measure derived from the ARCH model. The sample period used is 1964Q2 to 2001Q4 with a three-year rolling window. Appendix 1 outlines the SVAR methodology in greater detail.

7. We found that a four-quarter lag of the term structure seemed to perform best, which is the same finding as Cozier and Tkacz (1994).

8. Lagrange multiplier (LM) tests show the volatility clustering of an ARCH process of order one and thus reject the null hypothesis of constant conditional variance over a sample period 1965Q4 to 2001Q2. Lee (1991) showed that the LM tests for ARCH disturbances are identical to an LM test for GARCH disturbances. This leads us to adopt the GARCH (1,1) process, which is found to provide a good description of the data.

1.2 Description of the pattern of the uncertainty variables

The different measures of inflation and real uncertainty are portrayed in Figures 1 to 4. Beginning with the statistical measures of inflation uncertainty, they each suggest that inflation uncertainty has tended to decline over time (Figure 1). Thus, the spike in the moving average of the standard deviation of inflation was relatively high in the 1980s when inflation was also relatively high, and then moved down over the 1990s. The coefficient of variation followed a similar pattern, although it had a larger spike in the early 1990s than in the 1980s. This is not surprising. One might think that a one percentage-point change in inflation in the 1990s could generate more uncertainty than a similar variation in the 1980s, when the level of inflation was much higher.

By contrast, the survey-based measure has more or less remained constant at a low level from the mid-1980s, although there was an obvious shift downwards in the latter part of the 1990s. Overall, both the statistical and the survey-based measures point to relatively lower inflation uncertainty in the latter part of that decade and into the new millennium.

The regression measures of inflation uncertainty in Figure 2 typically reveal a more clear downward trend than the other uncertainty variables: the uncertainty variable derived from the SVAR model is an exception. The latter may be due to a number of factors, including the relatively high government debt-to-GDP ratio that drove up long-term real interest rates in the early to mid-1990s, and which are included in the SVAR. The GARCH measure suggests that uncertainty has fallen significantly when inflation appears to have shifted to another regime (Ricketts and Rose 1995), while the Christofides and Wilton (1983) measure has declined more or less continuously over time.

Statistical measures of real uncertainty (Figure 3) do not show as marked a decline as the inflation uncertainty measures. In addition, they are more narrowly dispersed around zero, although they show relatively more volatility around turning points. The survey-based measure also rose in the late 1990s around the time when the Canadian economy was being buffeted by the Asian and Russian crises.

Real uncertainty measures derived from econometric techniques exhibit relatively more dispersion than the statistical ones. Debs (2001) discovered a structural break in the variability of Canadian GDP growth in the second quarter of 1991. This appears consistent with the behaviour exhibited by the

Figure 1
Statistical measures of inflation uncertainty*

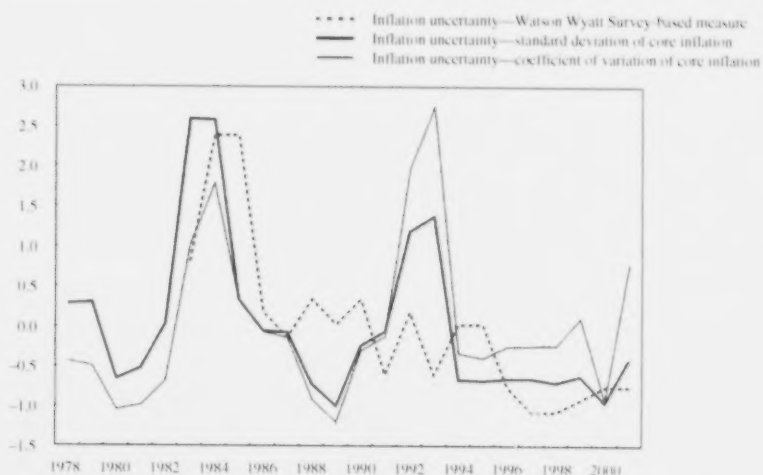


Figure 2
Econometric measures of inflation uncertainty*

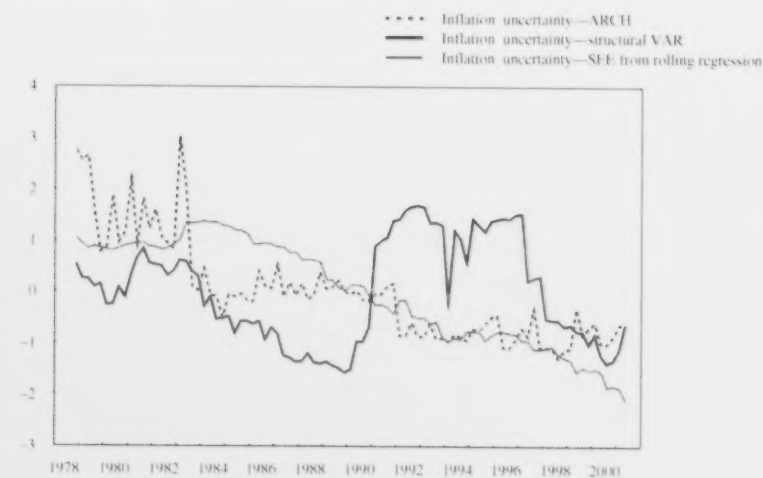


Figure 3
Statistical measures of real uncertainty*

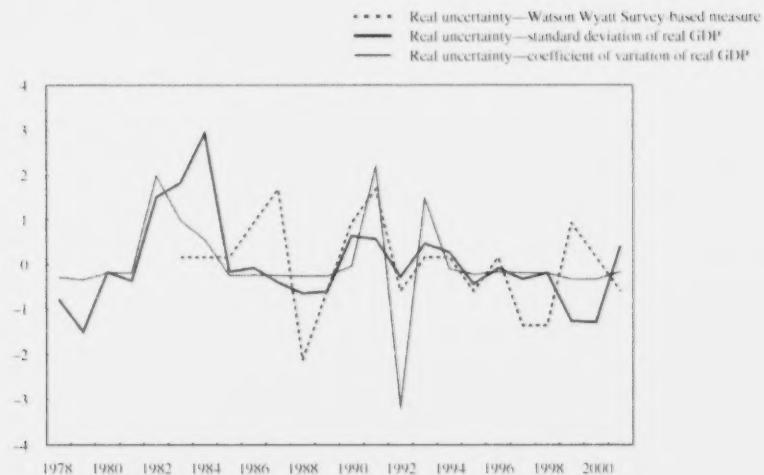
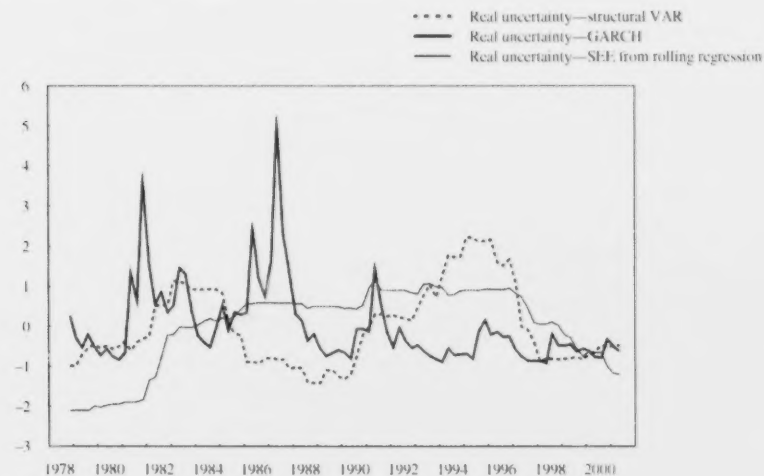


Figure 4
Econometric measures of real uncertainty*



GARCH measure of real uncertainty.⁹ By contrast, the SVAR measure of real uncertainty suggests relatively greater uncertainty in the 1990s. The rolling regression measure suggested by Murphy (2000) actually rose somewhat over time—consistent with the behaviour of the unemployment rate—and then fell sharply in the latter part of the 1990s, once again as the unemployment rate declined. By the late 1990s, all of the regression-based measures showed a relatively low level of uncertainty.

1.3 The pros and cons of each set of uncertainty indicators

The distinct behaviour among the uncertainty measures raises the obvious question of which are the most relevant to use in our empirical work. Unfortunately, there is no clear consensus in the literature. There are, however, clear advantages and disadvantages attached to each one (Table 1).

First, survey measures provide an obvious *ex ante*—what was known by the economic agents at the time of signing the contract—and a direct measure of uncertainty, since the survey measures are not revised and relate to the expectations of forecasters. Nevertheless, an important shortcoming of the Watson-Wyatt data is their annual frequency. In addition, the data range is limited, going back only to 1983. A more important limitation of the data is that they relate to the views of professional forecasters, and can be very sensitive to one forecast outlier. For this reason, we use the difference between the high and low quartile, and not the difference between the high and low forecasts. Nevertheless, there may also be respondents in the survey who do not give their best forecast because of strategic considerations or an incentive to publish a forecast that stands out. An implicit assumption for the use of this measure would be that it is widely known among bargaining parties, who use it as the basis for their negotiations.

Second, the statistical measures are easy to compute. But, as many authors have noted, a standard criticism of statistical measures of uncertainty is that at least a part of their variability is predictable (Stuber 2001). For example, some of the rise in statistical variability in the CPI in the first half of the 1990s was due to federal sales tax reform, which was announced well in advance of its implementation and therefore highly predictable. For that reason, we have used a measure of core inflation that excludes the impact of indirect taxes. Nevertheless, this measure still appears relatively volatile. On the positive side, given that the CPI is rarely revised, these measures can be

9. The real uncertainty measure based on GARCH techniques also reveals relatively high uncertainty in early 1987, which may be explained by the significant variability in real GDP growth at this time period. More precisely, real GDP quarterly growth (annual rates) went from -2.2 per cent in 1986Q4 to 9.0 per cent in 1987Q1.

Table 2
Summary statistics

Variable	Mean	Standard deviation	Minimum	Maximum
Duration (months)	30.4	10.59	5.0	72.0
Number of employees in BU	1,703	3,462.4	500	61,930
Change in number of employees	-28.3	667.4	-7,000	10,210
Incidence of cost of living agreements	0.30	0.46	0.0	1.0
Unemployment rate	9.3	1.64	6.7	12.9
Union density	36.0	0.02	24.0	38.0
Strike	0.11	0.08	0.02	0.28
Inflation uncertainty—3-year moving average of the standard deviation	0.7	0.7	0.02	2.5
Inflation uncertainty—3-year moving average of the coefficient of variation	0.2	0.1	0.006	0.5
Inflation uncertainty—survey-based measure	1.1	0.6	0.3	2.5
Inflation uncertainty—rolling regression	2.2	0.3	1.6	2.5
Inflation uncertainty—ARCH	1.4	0.8	0.4	3.8
Inflation uncertainty—SVAR	0.5	0.2	0.2	0.7
Real uncertainty—3-year moving average of the standard deviation	1.8	0.9	0.4	4.4
Real uncertainty—3-year moving average of the coefficient of variation	1.0	2.7	-7.1	6.6
Real uncertainty—survey-based measure	0.6	0.1	0.3	0.8
Real uncertainty—GARCH	0.4	0.2	0.3	1.4
Real uncertainty—SVAR	0.2	0.09	0.1	0.4

considered *ex ante* measures of uncertainty. This is not the case, however, for the GDP measure, which is a variable that is typically revised substantially over time.¹⁰

Third, although statistical measures are relatively easy to calculate, they are naive in the sense that they ignore the essential aspect of the agent's problem; that is, forecasting inflation. Regression methods explicitly model the forecasting problem of the agent and thus provide a better framework to measure inflation uncertainty. Still, it is unclear whether various econometric specifications capture how uncertainty is perceived by agents. Thus, a number of methods have been proposed.

The econometric measure developed by Christofides and Wilton (1983) is easy to calculate and varies over time as inflation changes. But an underlying assumption is a constant variance over time—which is not consistent with the data-generating process—and the choice of the lag

10. This problem could be overcome with the use of real-time GDP data, but at present we do not have a long enough time series for our work.

structure in the polynomial lag equation is basically arbitrary. A more refined measure can be created using GARCH techniques, but this methodology was not available at the time of the original Christofides and Wilton paper. It explicitly allows the modelling of the variance of inflation. The model used in this paper, however, assumes that positive and negative shocks on inflation raise the conditional variance by the same amount.¹¹ The inflation uncertainty measure is also sensitive to the model specification.¹² By contrast, the real uncertainty GARCH-based measure appears to be robust to different mean specifications of real output growth.¹³ Rich and Tracy argue that the SVAR approach has the relative merit of relying on measures that are aggregate in nature rather than on those based on single variables that may be too narrow in scope to be reliable proxies.

For these reasons, our preferred measures of uncertainty are those derived using regression techniques. Within these, the GARCH and SVAR techniques are chosen for the empirical analysis because they explicitly model the conditional variance and contain more of the variables that may play a role in the decision-making of agents. However, it is not clear which better captures uncertainty. We therefore present estimates for each in the analysis below. In Appendix 3, we provide information on the impact of the other uncertainty measures on contract duration.

2 Previous Empirical Research on Contract Duration Determinants

Empirical work on the determinants of labour contract duration began in earnest in Canada with Christofides and Wilton (1983). They used Canadian microdata from Labour Canada on wage contracts signed over the period 1966 to 1975 and found a negative relationship between contract duration and inflation uncertainty. The authors concluded that this negative relationship was most apparent when contracts were not indexed, but that it was still evident even when contracts had a cost of living adjustment (COLA). Christofides (1990) also found evidence for a negative relationship between inflation uncertainty and contract duration, although it was not significant at conventional levels.

11. In fact, more weight can be attributed to a positive shock to inflation uncertainty by using an asymmetric GARCH or a threshold GARCH.

12. Crawford and Kasumovich (1996) found relatively lower inflation uncertainty using a reduced-form Phillips curve model instead of an autoregressive process for the conditional mean function.

13. Adding the real exchange rate or a real non-energy commodity price index to the conditional mean function for real GDP does not significantly change the real uncertainty measure.

A relatively larger number of studies have been carried out with U.S. data. One of the earliest empirical papers to examine the impact of inflation uncertainty was Vroman (1989). She constructed a measure of inflation uncertainty using the coefficient of variation of inflation expectations derived from the Livingston Survey. Her estimation uncovered a significant negative link between it and contract duration. Using a measure of inflation uncertainty similar to that of Christofides and Wilton, Murphy (1992) also found a significant negative relationship between inflation uncertainty and contract duration. The first empirical study to address the issue of real uncertainty was by Wallace and Blanco (1991), who developed industry-specific measures of uncertainty based on producer prices at the sectoral level relative to the producer price index. Their measure of inflation uncertainty was derived from the standard error of a one-period-ahead money-supply forecast based on a simple autoregressive structure. They did not find a significant link between contract duration and either type of uncertainty. Wallace (2001) also did not find evidence of a clear-cut relationship between uncertainty and contract duration, regardless of the source of uncertainty. Murphy's (2000) results supported Danziger's efficient risk-sharing hypothesis, i.e., that real uncertainty leads to contracts of longer duration. In addition, greater inflation uncertainty (using the Christofides and Wilton measure) appeared to reduce the length of labour contracts.

Rich and Tracy (2000) expanded the analysis of contract duration to include a variety of real and nominal uncertainty measures to test the robustness of previous results with U.S. data on labour contracts. They found that the significance of uncertainty varied with the measure of uncertainty. For example, using the Christofides and Wilton measure, they discovered no evidence of a significant link between inflation uncertainty and contract duration. In contrast, survey-based measures of inflation uncertainty similar to those used by Vroman (1989) yielded a significant negative relationship, as did those based on either an ARCH or an SVAR methodology. As regards real uncertainty, contrary to the hypothesis of Danziger (1988), there was no evidence of a significant relationship with contract duration.

In summary, the existing literature, mainly in a U.S. context, reveals a lack of consistent results, suggesting that the impact of various forms of uncertainty on contract duration remains an open question. There are few studies to determine whether this is also the case in Canada. Moreover, it is unclear whether the inconsistent results are due to how uncertainty is constructed or to the role of uncertainty itself.

3 Stylized Facts on Contract Duration

The data for the study are derived from the Department of Human Resources Canada (HRDC) wage-settlements file. The data set contains 11,743 collective agreements in the private and public sectors covering 500 or more employees and beginning in 1978Q1. For our analysis, the data up to the second quarter of 2001 are used. The data set also includes the bargaining unit identifier, the number of employees, whether the contract includes a COLA clause, provincial and industry codes, and settlement, effective and expiry dates.¹⁴

In this paper, we focus only on the private sector and have excluded public sector contracts, which reduces the sample size to 4,644. The data for the public sector are substantially affected over time by institutional factors (such as wage freezes and suspension of collective bargaining), making them difficult to interpret. Owing to the inclusion of lagged data, the sample size is further reduced to 3,631 private sector agreements, beginning in 1978Q4.¹⁵ Figure 5 presents the annual average contract duration over time. While the trend is clearly upwards, there is a significant increase in the annual average duration in the private sector, particularly from 1996 to 2000. In comparison with the private sector, agreements in the public sector are approximately five months shorter.

Contracts are typically one, two, or three years in duration (77 per cent of all contracts fall into one of these groups). There is substantial evidence of staggered wage setting over time (not all contracts are one year in duration) and also within time periods (not all contracts are signed on the same date each year). The share of one-year contracts drops by almost 50 per cent between the pre- and post-inflation-targeting periods and longer contracts (greater than 36 months) have become more evident over the decade to 2001. Indeed, the average contract duration has risen by about eight months over the sample period.¹⁶ The annual average duration weighted by employees is almost the same as the unweighted duration (30.1 and 30.4

14. The settlement date is defined as the date when the contract is signed by the BU. The effective date is defined as the date when the provisions of the contract take effect, which can be either before, at the same time, or after the settlement date. In this paper, contract duration is calculated as the difference between the expiry date and the effective date, in months. For example, if a contract expires in $t + 36$ and $t + 60$, then the duration is 36 and 24 months, respectively.

15. The data set contains 3,631 agreements, representing 811 firms and union bargaining pairs, which means that on average each BU is present about 4.5 times in the data.

16. A study by HRDC (2001) found that small BUs (100 to 499 workers) had the highest proportion of collective agreements, with durations exceeding 36 months. Note that our data set does not include these small BUs.

Figure 5
Annual average contract duration



months, respectively) over the sample period (Table 2). On average, there are about 1,700 employees represented by a BU in the private sector and this number has fallen very slightly over time.

Contract length in the Atlantic region is slightly higher than the national average (32.9 versus 30.4 months) (Table 3). By industry, manufacturing represents 49 per cent of all agreements signed in the private sector (see Table 4). Both it and the primary industries sector have the longest average duration, about 31 months.

About 30 per cent of all private agreements contain a COLA clause, and these contracts are approximately five months longer than all other contracts. Roughly 70 per cent of COLA clauses are in relatively long duration contracts (36 months or more), which is consistent with the hypothesis that indexation and longer contracts go hand in hand. Figure 6 shows that the proportion of contracts with a COLA clause has decreased only slightly over time, with most of the reduction taking place in the 1980s. Interestingly, the incidence of a COLA clause did not change very much in the 1990s in the private sector. This suggests that unions, once having bargained for such a clause, would be reluctant to give them up even in a low inflationary environment.

Table 3
Regional distribution of agreements

Region	Proportion
Atlantic	0.060
Newfoundland	0.015
Prince Edward Island	0.001
Nova Scotia	0.026
New Brunswick	0.020
Quebec	0.212
Ontario	0.379
Prairies	0.110
Manitoba	0.033
Saskatchewan	0.017
Alberta	0.058
British Columbia	0.142
More than one province	0.097

Table 4
Industry distribution of agreements

Industry	Proportion
Primary industries	0.06
Utilities	0.03
Construction	0.14
Manufacturing	0.49
Wholesale and retail trade	0.10
Transportation	0.08
Information and culture	0.03
Finance, real estate, and management services	0.02
Education, health, and social services	0.01
Entertainment and hospitality	0.04

Figure 6
Annual proportion of COLA agreements



4 Estimation Techniques

The decision on the length of a labour contract signed by BUs is likely to depend on whether the agreement also contains a COLA clause. Thus, the estimation technique must account for this fact. Typically, the two-stage least-squares technique has been used (Vroman 1989; Murphy 1992), though more recent work has focused on the estimation of a simultaneous equation probit model, as proposed by Heckman (1978) and discussed in Maddala (1983). This type of model has several variations and two are examined in this paper.

The first model can be expressed as the following set of equations:

$$Dur_{it} = X_{1it}\alpha_1 + Cola_{it}\beta_1 + u_{1i}, \quad (1)$$

$$Cola_{it}^* = X_{2it}\alpha_2 + Dur_{it}\beta_2 + u_{2i}, \quad (2)$$

$$Cola_{it} = \begin{cases} 1 & \text{if } Cola_{it}^* > 0 \\ 0 & \text{if } Cola_{it}^* \leq 0 \end{cases}, \quad (3)$$

where Dur_{it} is a continuous variable of the duration of an agreement in months based on the settlement date; $Cola_{it}$ is a latent dependent variable measuring the propensity for a contract to be indexed, such that if $Cola_{it} = 1$, then the contract is indexed to the cost of living, and if $Cola_{it} = 0$, then it is not; X_{1it} is a vector of exogenous variables thought to affect the duration of an agreement, including the uncertainty measures; X_{2it} is a vector of exogenous variables for the cost of living decision (including the relevant uncertainty measures); and u_{1i} and u_{2i} are random disturbance terms.

As shown in Appendix 2, to estimate this model, a restriction must be placed on the coefficients (see Maddala 1983). This restriction is $\beta_1\beta_2 = 0$. Given that the goal of this paper is to examine contract duration, this restriction is imposed by setting $\beta_2 = 0$ in equation (2). The indexation equation is first estimated via a probit using maximum likelihood techniques. Then the duration equation (equation (1)), including the predicted values from equation (2), is estimated by OLS. This type of model has been used by authors such as Vroman (1989) and Rich and Tracy (2000).

In the second formulation, equation (1) is replaced by:

$$Dur_{it} = X_{1it}\alpha_1 + Cola_{it}\beta_1 + u_{1i}, \quad (4)$$

In this case, the latent dependent variable—the desire to index—enters into the equation directly. No similar coherency restriction is required in this model. The reduced form for equation (2) can then be estimated as a probit model using maximum likelihood techniques and equation (4) by ordinary least squares (OLS). The fitted values are then substituted back into the structural equations, which are estimated by OLS. This is the type of model estimated by Murphy (2000). Which model should be preferred is not clear. The second model does, however, allow the degree of indexation to affect the duration of a contract and thus may contain relatively more information than the binary variable. Further information on the methodologies is presented in Appendix 2.

In practice, the two methodologies generate very similar results. For that reason, we present the results for the first model below and outline the results of the other methodology in Appendix 3, Table A3.1. All continuous exogenous variables were standardized to zero mean and one standard deviation, while all of the regressions contain robust standard errors using the Huber-White estimator to correct for heteroscedasticity, which was

present in the residuals.¹⁷ Moreover, the estimation of the indexation equation contains additional variables thought to affect it, but not the duration decision. These are discussed further in Appendix 4.

5 Exogenous Variables in the Regression

In addition to uncertainty measures, a fairly standard set of variables is usually included in the analysis of the determinants of contract length. They typically proxy either some element of the costs of negotiation or the business cycle.

A set of aggregate variables was attached to each contract based on the settlement date of the contract. They include the national unemployment rate and the share of employed workers who are union members (union density).¹⁸ These variables take on their value for the quarter in which the contract was signed.

The inclusion of the unemployment rate serves two purposes. Christofides and Stark (1996) used it to proxy union bargaining power. A lower unemployment rate should reflect greater union bargaining power, and therefore reduce contract duration. On the other hand, Vroman (1989) included the unemployment rate as a measure of tightness of the labour market and found that contract duration was procyclical, i.e., workers seek to lock in gains in tighter labour markets through longer contracts.

The union density variable captures union bargaining strength. Indeed, Murphy (1992) argues that a key concession by a union is a longer contract, thus a decline in union bargaining strength should lead to relatively longer contracts.

Uncertainty measures are appended using the methodologies outlined above. Additional variables, described below, come from the wage data set itself.

The number of employees covered by each BU is often used as a proxy for several facets of the negotiation process, and as such, the expected sign on its coefficient is indeterminate. First, it is used to proxy negotiation or transactions costs. Larger BUs may have scale economies in negotiation, suggesting a negative coefficient. On the other hand, larger BUs may also have more complex negotiations and thus higher costs, suggesting a positive

17. We also corrected the standard errors for any non-independence of observations across BUs. Although the standard errors were different for some of the coefficients, this did not affect inference, i.e., variables that were significant remained significant, so we do not report these results.

18. The unemployment rate by industry would better relate to specific industry conditions, but data only begin in 1987.

coefficient. Second, it may reflect bargaining power. Murphy argues that unions are more risk-averse than firms.¹⁹ Greater bargaining power by unions would therefore tend to lead to shorter contracts. The change in the number of employees in the BU between two agreements is included to account for membership changes. For example, declines are expected to be associated with longer contracts as unions (with less bargaining power) attempt to lock in gains over a longer period of time (Rich and Tracy 2000).

Indexation is an alternative way of dealing with uncertainty. Results from previous studies (Vroman 1989; Christofides 1990; Rich and Tracy 2000) have found a significant positive relationship between cost of living indexation and contract duration, consistent with the view that longer contracts are more likely to be indexed, helping to ensure the bargaining unit against unfavourable price movements.

A trend variable is included in the regressions to account for the general upward movement in contract duration in the sample period. We include this as the year a contract was signed. Nevertheless, given that this upward trend was most apparent in the 1990s, in one specification, this variable is replaced with a dummy variable taking on the value of one for the period 1992 to present, and zero otherwise. Use of this variable is consistent with work done by Ricketts and Rose (1995), who estimated a Markov-switching model and found that the Canadian inflation process can be split into three distinct regimes, one of which is a low-inflation period beginning in 1992. In addition, the inclusion of this variable is also consistent with the notion that uncertainty is related to the inflation regime as well, and not solely to the level of inflation (O'Reilly 1998).

Finally, two different sets of dummy variables are used in the regression analysis. First, it is likely that contract duration varies across industries. A set of industry dummy variables is therefore included to capture aspects of contracting costs not taken into account by other variables (fixed effects).²⁰ Industry dummies also capture variation in bargaining power across sectors. Production functions differ among industries, and the bargaining power of a BU probably depends positively on the importance of labour input in the production process. Manufacturing is the excluded sector. Second, a set of

19. Larger firms may have more resources and staff to bargain with unions. In addition, small firms might be more risk-averse than large firms, and prefer to sign shorter contracts that allow them the option of revising the terms of agreements more frequently.

20. The industries are entertainment and hospitality; finance, insurance, and real estate; health and education; information and communications; primary, retail, and wholesale trade; manufacturing; and transportation.

regional dummy variables is included to capture the heterogeneity in settlements across Canada, with Ontario being the excluded province.²¹

Due to the nature of our data set, certain variables that could help clarify the contract duration decision are unavailable. Most of these proxy economic conditions at the firm level.²² Nevertheless, to the extent that the variables are industry specific, they should be picked up in the industry fixed effects (dummy variables).

6 Estimation Results

Table 5 presents the estimation results for the duration equation of the first model. As a first step, we began by including the inflation/nominal uncertainty measures only (in addition to the other exogenous variables). The coefficients on the inflation/nominal uncertainty measures are negative and significant, suggesting that declining uncertainty of this form has been associated with greater contract length. This negative relationship is consistent with the findings of many other authors. In particular, the regression with the GARCH measure of inflation uncertainty indicates that a one standard deviation increase in inflation uncertainty decreases contract length by about one month. The SVAR uncertainty measure suggests an effect of about two-thirds that of the GARCH uncertainty measure.

Table 6 presents the same equations, but now including the real uncertainty measures. There is little change in the coefficients on the inflation/nominal uncertainty measures. The real uncertainty measures, however, are not significant. Note that for the SVAR measure, we have removed the unemployment rate variable, which was very highly correlated with the real uncertainty measure. In general, these results provide little support for the notion that real uncertainty—at least as defined here—plays an important role in contract duration.

Turning to the other explanatory variables, the coefficient on COLA (predicted values) is positive and significant, indicating that indexation leads to longer contracts, *ceteris paribus*. The impact is similar across specifications, and indicates that contracts with COLA clauses are close to five months longer than those without such a clause. Longer contract duration for agreements with COLA clauses has also been found by other authors (Christofides and Wilton 1983; Vroman 1989; Rich and Tracy

21. The regions are the Atlantic provinces, Quebec, Ontario, the Prairie provinces, and British Columbia. In addition, a dichotomous variable is included to capture contracts that are in effect in more than one region.

22. An obvious candidate is corporate profits by industry, but data begin only in 1988, not long enough a time period for our analysis.

Table 5
Estimation results: inflation/nominal uncertainty

	1	2	3	4
COLA	4.8 (0.49)**	4.7 (0.49)**	4.8 (0.49)**	4.7 (0.49)**
Unemployment rate	-1.3 (0.17)**	-0.88 (0.20)**	-2.1 (0.19)**	-1.2 (0.20)**
Union density	0.33 (0.19)	0.46 (0.19)**	0.50 (0.21)**	1.2 (0.19)**
Number of employees	-0.26 (0.19)	-0.25 (0.19)	-0.28 (0.19)	-0.30 (0.19)
Change in employment levels	0.23 (0.15)	0.23 (0.15)	0.23 (0.15)	0.19 (0.15)
Trend	0.60 (0.05)**	0.75 (0.03)**		
Dummy variable for low inflation period			4.8 (0.46)**	10.3 (0.45)**
GARCH inflation uncertainty	-0.99 (0.26)**		-2.4 (0.21)**	
SVAR nominal uncertainty		-0.64 (0.17)**		-2.4 (0.21)**
F-statistic (industry)	9.4	9.3	8.3	7.8
F-statistic (regional)	12.4	12.7	11.4	11.6
R squared	0.24	0.24	0.24	0.24

Notes: Huber-White robust standard errors reported.

** denotes significance at the 5 per cent level.

2000). The coefficient on the unemployment rate is negative and significant, consistent with the finding of Vroman that when labour markets are tight, workers seek to lock in gains through longer contracts. The size of the BU, and its change, appear to have no significant impact on contract duration. This suggests that there are few economies of scale in the bargaining process and that membership changes have not led unions to seek longer contracts. The union density variable is positive and its coefficient typically significant, lending support to the notion that greater union strength leads to a lengthening in contract duration (the opposite of what Murphy (1992) hypothesizes). The coefficient on the trend variable is positive and significant, indicating that contract length has risen about 0.7 months per year. In addition, this trend variable is highly significant and accounts for about half of the explanatory power of the regressions. Moreover, it is noteworthy that the inflation uncertainty variable is still significant, even when a trend variable is included.

While the coefficients on the dummy variables are not reported, they are jointly significant as a group (i.e., by industry and by region). They reveal

Table 6
Estimation results: all uncertainty measures

	1	2	3	4
COLA	4.8 (0.49)**	4.6 (0.49)**	4.8 (0.49)**	4.7 (0.49)**
Unemployment rate	-1.3 (0.17)**		-2.1 (0.19)**	
Union density	0.36 (0.19)	0.47 (0.19)**	0.50 (0.21)**	1.2 (0.18)**
Number of employees	-0.26 (0.19)	-0.25 (0.19)	-0.28 (0.19)	-0.30 (0.19)
Change in employment levels	0.23 (0.15)	0.22 (0.15)	0.23 (0.15)	0.19 (0.15)
Trend	0.59 (0.05)**	0.73 (0.03)**		
Dummy variable for low inflation period			4.8 (0.49)**	10.0 (0.48)**
GARCH inflation uncertainty	-0.95 (0.26)**		-2.4 (0.21)**	
GARCH real uncertainty	-0.23 (0.15)		0.01 (0.15)	
SVAR nominal uncertainty		-1.1 (0.21)**		-2.9 (0.23)**
SVAR real uncertainty		0.29 (0.23)		0.04 (0.24)
F-statistic (industry)	9.3	9.2	8.3	7.7
F-statistic (regional)	12.4	12.5	11.4	11.4
R squared	0.24	0.24	0.23	0.23

Notes: Huber-White robust standard errors reported.

** denotes significance at the 5 per cent level.

that (relative to Ontario) contract duration is significantly greater in Quebec and the Atlantic region, but significantly lower in Alberta, after controlling for other factors. By industry (relative to manufacturing), contract duration is significantly lower in construction, health and education, as well as utilities, but not significantly different for the remaining industries.

As noted, we replaced the trend variable with a dummy variable taking on the value of one for the time period from 1992. These results are presented in equations (3) and (4) in Table 5. The coefficient on this dummy variable is positive and highly significant (similar to the trend measure), indicating an upward shift in contract duration in the inflation-targeting period. Although this coefficient is well determined within each regression, its amplitude varies depending on the set of uncertainty measures. It is lowest with the GARCH uncertainty measures and highest with the SVAR measure, the

latter indicating an increase of about 10 months in the inflation-targeting period.

To check for differences in the slope coefficients, we interacted the dummy variable for the low-inflation period with the inflation uncertainty measures. In the case of the GARCH measure, the coefficient on the interaction term is insignificant. In the case of the SVAR measure, however, the coefficient is significant and negative. This suggests that the relationship between contract duration and uncertainty has become more negative over time.

In summary, the results of the estimation provide considerable support for the notion that lower inflation/nominal uncertainty leads to contracts of longer duration. By contrast, there appears to be little link between real uncertainty and contract duration in the Canadian context. In addition, the results also suggest that contract duration has become longer over the period in which the inflation-targeting regime has been in place. Appendix tables A3.2 and A3.3 provide some sensitivity analysis, using the other measures of uncertainty outlined above. The results vary depending on whether the trend term or the dummy variable is included in the regressions as well as how uncertainty is measured.

Finally, the overall explanatory power of the regressions is not high and it is worth highlighting that more information at the BU level might help to increase the explanatory power of the regressions. One shortcoming of the data set is that it pertains only to large firms where differences across BUs may not be large. Similarly, the sample period is relatively short and does not include the oil-price shocks of the 1970s when inflation began to rise significantly.

7 Conclusions and Some Implications of Longer Contract Duration

Our results confirm the findings of other studies in both Canada and the United States that falling inflation uncertainty leads to contracts of longer duration. And similar to papers examining U.S. data, there remains doubt about the role for real uncertainty in the duration decision. When the list of uncertainty measures is broadened to include those derived from simple filters or survey-based data, the results become much less certain. There are good reasons, however, to prefer the results from uncertainty measures developed through regression techniques.

Nevertheless, additional work could be done to refine the uncertainty measures. For example, the inflation and real uncertainty measures could be jointly estimated in a GARCH-in-mean framework (e.g., Grier and Perry

2000), which may lead to more efficient estimates, although it is not clear that this would change the behaviour of the measures, or the results that much. As noted above, the sample period could also be extended back to the 1960s to obtain more variation in the data, and to help verify the role of uncertainty in contract duration. This may be possible in the Canadian context by linking the database used in this study with those used in previous Canadian studies, such as Christofides and Wilton (1983). It would also be useful to increase the richness of the database with other variables concerning the bargaining process and economic conditions at the time a contract is signed, to the extent that it is possible. This might help to boost the explanatory power of the regressions.

As regards the implications of our results, we confine them to three areas: endogeneity of the contract duration decision, generalizing the results to price-level targeting, and economic welfare.

7.1 Endogenous vs exogenous contract duration

The duration of labour agreements is important for the efficiency of monetary policy because such contracts limit the ability of firms and workers to respond to adverse shocks. As Fischer (1977) noted, this provides the monetary authority with the opportunity to stabilize output even in a rational-expectations setting. In particular, he shows that a role for stabilization policy is created by long-term wage contracts where wages are predetermined in a rational-expectations framework. Thus, longer contracts emerging from falling inflation uncertainty since the early 1980s have potentially increased nominal rigidity in the economy and the stabilization role for monetary policy.

A key assumption by Fischer, however, is that contract length is exogenous. This is also the assumption by authors of papers that use Calvo (1983)-style contracts to model the wage-setting decision. Our results, however, suggest that the decision on the duration of a contract, and thus when wages will be renegotiated, is contingent on the amount of inflation uncertainty in the economy, as suggested by Gray (1978) and Canzoneri (1980). Therefore, when inflation uncertainty is high, BUs are more likely to agree to shorter contracts, *ceteris paribus*. This would imply that wages would be set more frequently. Consequently, the results of this paper lend support to the notion that contract length is endogenous in the Canadian context. Taylor (1999) summarizes papers that have come to the same conclusion for other countries, but there appears to have been little work incorporating endogenous contract length. He notes, however, that there has been a relatively recent move to create models with "state-dependent pricing," i.e., where contract duration is contingent on the state of the economy. This is an

area that could be explored further by examining the role of nominal-wage rigidities in the presence of endogenous contract duration and the implications for inflation dynamics.

In addition, our results indicate that the duration of contracts varies slightly by sector and while the paper does not address the underlying factors that account for this directly, this nevertheless implies that the impact of monetary policy by sector would be different. While it may appear obvious that monetary policy affects sectors differently (see Farès and Srouf 2001), contract duration provides an additional reason why this might be so. A surprising finding, however, is that contract duration is not markedly different among each of the sectors. Indeed, it was only found to be significantly different from the manufacturing sector solely for construction, health and education, and utilities.

An interesting question is that to the extent that nominal rigidity in the economy has increased because of longer duration contracts, why has there not been relatively more output variability? Indeed, even if nominal rigidity has increased, this suggests that it may not pose a problem for the conduct of monetary policy. In the Canadian monetary policy regime, a key role is undoubtedly played by the flexible exchange rate, which tempers the declines in output and employment that would have to come about because of negative economic shocks. But other factors have probably been at play as well, including better inventory management, fewer relative price shocks, the changing structure of the Canadian economy, and better conduct of monetary policy (Debs 2001; Longworth 2002). Of course, nominal-wage rigidity may not have increased all that much. Indeed, the contracts examined cover only a small portion of employment since the unionized sector makes up only about 30 per cent of paid employees, and this share has changed very little over the sample period. Moreover, the focus in this paper was only on the private sector. Wage-setting may also have become more synchronized, which would tend to reduce inertia stemming from staggered contracts. Nevertheless, to the extent that these agreements are similar in nature to the private non-unionized sector would suggest that the results might hold more generally (Taylor 1999). Unfortunately, there is a lack of data that would allow a more detailed look at wage-setting practices. More research is needed in this area, as well as an examination of the link between output and inflation variability.

Indexation also helps to offset nominal inertia. However, as discussed in Appendix 4, there has been little change in the incidence of indexation in the private sector, and we find few statistically significant variables that help to explain the indexation decision. Moreover, it is important to note that while price indexation may reduce nominal inertia, it also aggravates the impact of

real shocks on the economy. For example, in the case of a negative supply-side shock, prices rise and output falls. In an indexed contract, wages would rise at the same time that output is falling, exacerbating the negative impact of the shock and likely requiring greater employment declines than would otherwise be the case. There is insufficient information on BU agreements to determine whether they contain clauses linked to real factors.

Besides the macroeconomics factors discussed above, there are several other reasons why workers and firms sign agreements, either explicit or implicit. For example, it is not solely bargaining costs associated with uncertainty that lead firms and workers to contract. Indeed, large fixed costs due to hiring and firing encourage firms and workers to agree to labour contracts of greater duration, especially for skilled workers. Firms may also set wages and labour contracts based on efficiency wage concerns to solicit work effort or reduce shirking. To the extent that it is possible, incorporating more features of why firms and workers agree to contracts into the analysis would also be useful and would allow a check on the robustness of the results related to the uncertainty variables.

7.2 The policy framework

Given that under the Bank of Canada's inflation-targeting regime, uncertainty about inflation appears to have fallen and contract duration lengthened, would a move to a price-level target lead to results similar to those in this paper, i.e., would a price-level target reduce uncertainty further and thus boost contract duration? Unfortunately, there is no clear-cut answer to that question. Conventional wisdom has been that to stabilize the price level, higher than average inflation must be followed by lower than average inflation to meet the price-level target. This would then result in higher inflation variability than inflation targeting, since under the latter, bygones are bygones. Indeed, as Stuber (2001) notes, it may be easy to predict the inflation rate under certain circumstances, but the degree of unpredictability of the price level over longer time periods would remain quite high because of base period drift. A number of different authors have, however, challenged this view, arguing that it depends on a number of factors, for example, the amount of persistence in output, the extent to which expectations are forward- or backward-looking, assumptions made about the type of Phillips curve, and so on (Svensson 1996; Kiley 1998; Maclean and Pioro 2001; Srouf 2001).

7.3 Economic welfare

One of the key gains from longer contract duration is likely to be lower transactions costs for the economy, *ceteris paribus*, and thus a welfare gain. Indeed, with longer contract duration, economic agents spend less time, effort, and money to deal with more predictable inflation. Another benefit is the reduction in costs from labour market disputes such as the loss of output due to strikes. And as Longworth (2002) notes, there is less need to protect oneself against unexpected inflation, which means another savings in resources.

Appendix 1

Structural VAR Estimation

An SVAR model is adopted to calculate measures of nominal and real uncertainty. This methodology has been proposed by Gali (1992) and Rich and Tracy (2000). This framework allows for the identification of structural shocks by decomposition. The SVAR includes five variables to identify both nominal and real shocks, which is an advantage over other measures of uncertainty that are based on a single variable. Obviously, our variable of interest, real chain-weighted GDP, is included. The nominal variable is total CPI year-over-year, which allows us to distinguish between nominal and real shocks. The unemployment rate is included because of its information content for economic activity. Finally, the real day-to-day loan rate and the real 10-year-plus government bond yield are included because of their importance in helping to explain both monetary and fiscal policy changes and long-term investment decisions. All variables are transformed if necessary in order to be stationary and are ordered in the SVAR. Eight lags are used to eliminate serial correlation from the residuals.

The shocks and the variables for the structural model can be summarized as follows:

$$\epsilon_t = \begin{bmatrix} \epsilon_s \\ \epsilon_{d1} \\ \epsilon_{d2} \\ \epsilon_{d3} \\ \epsilon_{d4} \end{bmatrix} \text{ and } Z_t = \begin{bmatrix} \Delta GDP \\ \Delta \pi \\ \Delta u \\ r_{rt} \\ r_{lt} \end{bmatrix}, \quad (A1.1)$$

where it is assumed that real GDP can be decomposed into one permanent component and four transitory components. Thus, a minimum of identifying restrictions are imposed on the variance-covariance matrix of the vector of structural innovations. It is assumed that only the supply shock has a permanent effect on the level of real GDP, while demand shocks have a transitory effect and no long-run impact on real GDP. This hypothesis gives us four restrictions. We add others to separate the four demand shocks. Under such assumptions, the matrix of long-run effects is lower triangular. The structural model is therefore identified using the Blanchard and Quah decomposition:

$$\begin{bmatrix} \epsilon_s & \epsilon_{d1} & \epsilon_{d2} & \epsilon_{d3} & \epsilon_{d4} \end{bmatrix} \\
 \begin{bmatrix} GDP \\ \pi \\ u \\ FF_{st} \\ FF_{lt} \end{bmatrix} \begin{bmatrix} r_{11} & 0 & 0 & 0 & 0 \\ r_{21} & r_{22} & 0 & 0 & 0 \\ r_{31} & r_{32} & r_{33} & 0 & 0 \\ r_{41} & r_{42} & r_{43} & r_{44} & 0 \\ r_{51} & r_{52} & r_{53} & r_{54} & r_{55} \end{bmatrix} = \Gamma(1).$$

Impulse-response functions of real GDP from this SVAR reveal that transitory shocks have a standard hump-shaped form, and the effect of those shocks dissipates over time. The supply shock has an effect on the level of real GDP, which cumulates steadily over time.

More importantly for uncertainty, the SVAR is an attractive model since uncertainty measures can be calculated by using the five types of shocks. The real uncertainty measure is defined to be a weighted sum of ϵ_s and ϵ_{d2} . The nominal uncertainty variable is defined as a weighted sum of three shocks: the monetary shock, ϵ_{d1} , and the two remaining demand shocks, ϵ_{d3} and ϵ_{d4} . Note that the sum of different shocks is weighted by their respective variance (not normalized), i.e., each shock is weighted by the diagonal elements of the contemporaneous variance-covariance matrix. Then, a three-year moving-average standard deviation of this weighted sum gives the uncertainty measures. The choice of a three-year rolling window is based on the response of the level of real GDP to a permanent shock.

Appendix 2

Econometric Methodology

A method used widely in the literature is the simultaneous probit developed by Heckman (1978), which treats the COLA decision as a latent dependent variable. The framework is as follows:

$$Dur_{it} = X_{1it}\alpha_1 + Cola_{it}\beta_1 + u_{1it}, \quad (A2.1)$$

$$Cola_{it}^* = X_{2it}\alpha_2 + Dur_{it}\beta_2 + u_{2it}, \quad (A2.2)$$

$$Cola_{it} = \begin{cases} 1 & \text{if } Cola_{it}^* > 0 \\ 0 & \text{if } Cola_{it}^* \leq 0 \end{cases} \quad (A2.3)$$

Because of the latent dependent variable, Heckman notes that for this system to be identified (or coherent), a restriction must be imposed. He calls this the *principle assumption* and it is $\beta_1\beta_2 = 0$. To see why this must be the case, substitute Dur_{it} into $Cola_{it}^*$, which gives:

$$Cola_{it}^* = Cola_{it}\beta_1\beta_2 + X_{1it}\beta_2\alpha_1 + X_{2it}\alpha_2 + u_{1it}\beta_2 + u_{2it}.$$

When $Cola_{it} = 0$, then

$$-(X_{1it}\beta_2\alpha_1 + X_{2it}\alpha_2) \geq u_{1it}\beta_2 + u_{2it}.$$

When $Cola_{it} = 1$, then

$$-(X_{1it}\beta_2\alpha_1 + X_{2it}\alpha_2) - \beta_1\beta_2 < u_{1it}\beta_2 + u_{2it}.$$

For logical consistency, this implies that $\beta_1\beta_2 = 0$. This restriction is imposed for estimation, i.e., we assume that $\beta_2 = 0$.

In the first stage, equation (A2.2) is a probit equation estimated by maximum likelihood techniques, and the predicted values are generated for $Cola_{it}^*$. In the second stage, they are substituted into equation (A2.1), which is then estimated by OLS (see Maddala 1983).

Another way to estimate the model is to allow the latent dependent variable, $Cola_{it}^*$, to enter the system directly. Thus, equation (A2.1) becomes:

$$Dur_{it} = X_{1it}\alpha_2 + Cola_{it}^*\beta_1 + u_{1it}. \quad (A2.4)$$

The methodology (see Maddala 1983) is to then estimate the reduced forms of equations (A2.2) and (A2.4):

$$Dur_{it} = X\Pi_{dur} + v_{1it}, \quad (A2.5)$$

$$Cola_{it}^* = X\Pi_{cola} + v_{2it}, \quad (A2.6)$$

where the vector X contains all exogenous variables in the system. Equation (A2.5) is estimated by OLS, and equation (A2.6) is a probit equation estimated by maximum likelihood techniques. The predicted values for Dur_{it} and $Cola_{it}^*$ are then substituted back into the structural equations, which can be estimated by OLS. There is, however, an additional complication. Because $Cola_{it}^*$ is unobserved, equation (A2.2) must be normalized and estimated by OLS.

$$Dur_{it} = Cola_{it}^*(1/\beta_2) - X_{2it}(d_2/\beta_2) - u_{2it}/\beta_2, \quad (A2.7)$$

where $Cola_{it}^*$ can be derived from equation (A2.6).

Equation (A2.7) can then be solved for the coefficients α_1/β_2 and $1/\beta_2$ to generate the structural parameters of equation (A2.2). Since the focus of this paper is on contract duration, this second step was not carried out for the COLA equation.

Another issue in the methodology is the extent to which an additional—potentially endogenous—variable, wages, should be entered into the system. Its exclusion would lead to biased estimates to the extent that it should be included. Adding a wage equation into the system is a relatively straightforward extension to each of the models outlined above. We attempted to incorporate it into the system containing the GARCH measures of uncertainty. However, we encountered problems with multicollinearity between the wage variable and the GARCH measure of inflation uncertainty. Not surprisingly, nominal-wage changes have fallen in step with lower inflation uncertainty. Indeed, the correlation between the two variables is over 0.7. Thus, each measure basically tells the same story when included in the duration equation.

Appendix 3

Additional Estimation Results

Table A3.1
Estimation results of duration equation: Model 2 formulation

	1	2	3	4
COLA	4.8 (0.48) ^{***}	4.5 (0.49) ^{***}	4.9 (0.49) ^{***}	4.7 (0.49) ^{***}
Unemployment rate	-1.2 (0.17) ^{***}		-2.0 (0.19) ^{***}	
Union density	0.27 (0.19)	-0.15 (0.16)	0.41 (0.21)	0.43 (0.16)
Number of employees	-0.26 (0.19)	-0.25 (0.19)	-0.28 (0.19)	-0.30 (0.19)
Change in employment levels	0.23 (0.15)	0.25 (0.15)	0.23 (0.15)	0.24 (0.15)
Trend	0.59 (0.05) ^{***}	0.76 (0.03) ^{***}		
Dummy variable for low inflation period			4.8 (0.49) ^{***}	10.6 (0.47) ^{***}
GARCH inflation uncertainty	-0.99 (0.26) ^{***}		-2.4 (0.21) ^{***}	
GARCH real uncertainty	-0.23 (0.15)		0.02 (0.16)	
SVAR inflation uncertainty		-1.2 (0.21) ^{***}		-3.0 (0.22) ^{***}
SVAR real uncertainty		0.43 (0.24)		0.17 (0.24)
R squared	0.24	0.24	0.23	0.23

Notes: Hubert-White standard errors reported.

*** denotes significance at the 5 per cent level.

Table A3.2

Estimation results: Non-regression-based uncertainty measures

	1	2	3	4	5	6
COLA	4.6 (0.49) ^{***}	4.7 (0.49) ^{***}	4.1 (0.57) ^{***}	4.7 (0.50) ^{***}	4.5 (0.50) ^{***}	4.2 (0.57) ^{***}
Unemployment rate	-1.5 (0.21) ^{***}	-1.3 (0.21) ^{***}	-0.29 (0.40)	-2.4 (0.23) ^{***}	-2.2 (0.21) ^{***}	-1.4 (0.43) ^{***}
Union density	0.47 (0.21)	0.53 (0.19) ^{***}	-1.4 (0.74)	0.90 (0.21) ^{***}	1.3 (0.19) ^{***}	-2.0 (0.72) ^{***}
Number of employees	-0.25 (0.19)	-0.24 (0.19)	-0.28 (0.19)	-0.25 (0.19)	-0.25 (0.20)	-0.31 (0.19)
Change in employment levels	0.22 (0.15)	0.23 (0.15)	0.24 (0.16)	0.19 (0.16)	0.19 (0.16)	0.22 (0.16)
Trend	0.75 (0.03) ^{***}	0.70 (0.04) ^{***}	0.79 (0.07) ^{***}			
Dummy variable for low inflation period				9.2 (0.47) ^{***}	9.8 (0.71) ^{***}	6.3 (0.57) ^{***}
Moving average: sid deviation CPI	0.47 (0.21)			-1.4 (0.24) ^{***}		
Moving average: sid deviation GLP	0.07 (0.27)			1.4 (0.32) ^{***}		
Coefficient of variation: CPI		0.21 (0.22)			-0.93 (0.33) ^{***}	
Coefficient of variation: GLP		-0.37 (0.15)			0.40 (0.16) ^{***}	
Survey CPI			0.91 (0.34) ^{***}			0.17 (0.31)
Survey GLP			-0.09 (0.19)			0.32 (0.21)
R squared	0.21	0.24	0.21	0.22	0.21	0.21

Notes: Hubert-White standard errors reported.

*** denotes significance at the 5 per cent level.

Table A3.3
Estimation results: Rolling-regression-based
uncertainty measures

	1		2	
COLA	4.6	(0.49)**	4.6	(0.49)**
Unemployment rate	-1.1	(0.18)**	-2.0	(0.21)**
Union density	0.47	(0.19)**	0.78	(0.20)**
Number of employees	-0.24	(0.19)	-0.25	(0.20)
Change in employment levels	0.22	(0.15)	0.21	(0.16)
Trend	0.86	(0.10)**		
Dummy variable for low inflation period			3.4	(0.74)**
Rolling regression: inflation	0.77	(0.50)	-2.3	(0.39)**
Rolling regression: real	-0.22	(0.24)	1.1	(0.18)**
R squared	0.24		0.23	

Notes: Hubert-White standard errors reported.

** denotes significance at the 5 per cent level.

Appendix 4

The COLA Equation

While not the focus of this paper,¹ the estimation methodology allows us to examine the determinants of the inclusion of COLAs in contracts. The indexation equation contains additional variables thought to affect it and not the duration decision. These regressors act as instruments that help to disentangle the COLA and duration decisions. To some extent, the decision on which variables to include in each stage (and to exclude from the other) is arbitrary, and economic theory provides only partial guidance. Bearing this in mind, the unemployment rate was excluded, and additional instruments that were included in the first-stage COLA equation (but not in the duration equation) were: whether the previous contract contained an indexation clause, the year-over-year rate of inflation at the time the contract was signed, a measure of strike activity, whether the agreement was the first one signed between the firm and union, and whether it was the first one signed in the 1990s.

The latter two variables were included to proxy transactions costs. If it is the first time a contract has been signed between bargaining parties, then they might be more likely to put in a COLA clause. On the other hand, if it is the first contract signed in the 1990s, then the coefficient might be negative, given lower inflation uncertainty. Whether the previous contract contained a COLA clause was also added to account for bargaining costs. If the previous contract contained a COLA clause, then bargaining costs are likely to be lower. The inflation variable serves as a proxy for expected inflation. Various authors have argued that it should play no role in this equation because what matters is not the expected level of inflation, but its variability (Ragan and Bratsberg 2000). Nevertheless, since the empirical evidence is mixed, we incorporate it in the equation. The strike activity variable is defined as the percentage of estimated working time loss due to strikes² and is also included to proxy bargaining costs. Finally, the COLA equation contains only a measure of inflation uncertainty, and no real uncertainty variable, because a COLA clause relates primarily to inflation uncertainty.

As seen in Appendix Table A4.1, to a large extent the main explanatory power for COLA comes from the lagged dependent variable and the union variable. In addition, the industry-regional dummy variables are jointly significant. Thus, the incidence of a COLA clause is likely to be lower

1. A few empirical studies have dealt with the indexation issue, such as Cousineau, Lacroix, and Bilodeau (1983) and Christofides and Stark (1996).

2. More specifically, the percentage of estimated working time is paid employees divided by workers involved in strikes, weighted by the days of work during a year.

(relative to manufacturing) in construction, retail and wholesale trade, and entertainment and hospitality industries. By region, the incidence is significantly lower in Alberta. Unlike the case of the duration equation, however, the inflation uncertainty measures are seldom significant, but where they are significant, the coefficient is negative, a surprising finding because it indicates that indexation rises as uncertainty falls. At first glance, these results may appear surprising. But it should be borne in mind that over the sample period used in this study, the incidence of a COLA clause in *private* sector contracts was virtually unchanged.

Table A4.1
Estimation results of the COLA equation

	1	2	3	4	5
Number of employees	0.04 (0.03)	0.04 (0.03)	0.04 (0.03)	0.04 (0.03)	0.04 (0.03)
Change in employment levels					
CPI	0.03 (0.03)	0.03 (0.03)	0.03 (0.03)	0.03 (0.03)	0.03 (0.03)
Union	0.04 (0.03)	0.02 (0.03)	0.00 (0.03)	0.02 (0.03)	0.01 (0.03)
Strike	-0.12 (0.03)**	-0.14 (0.03)**	-0.11 (0.03)**	-0.11 (0.03)**	-0.07 (0.07)**
Lag COLA	0.06 (0.05)	0.10 (0.04)**	0.10 (0.04)**	0.06 (0.04)	-0.10 (0.06)
GARCH inflation uncertainty	2.4 (0.07)**	2.4 (0.07)**	2.4 (0.07)**	2.4 (0.07)**	2.5 (0.09)**
SVAR inflation uncertainty	0.09 (0.05)				
Moving average std deviation		0.05 (0.03)			
CPI			-0.06 (0.04)		
Moving average coefficient of variation CPI				-0.09 (0.04)**	
Survey CPI					-0.08 (0.05)
Rolling CPI					
F-statistic (industry)	91.9	53.9	56.2	54.8	36.1
F-statistic (region)	36.8	22.9	23	23.3	20.5
					22.6

Notes: Hubert-White standard errors reported.

** denotes significance at the 5 per cent level.

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Discussion

John Knowles

It is helpful to think of this paper as an empirical application of the Gray (1978) model. This is not an entirely accurate view, however, since the authors also discuss some of the more recent refinements of Gray's analysis, but the Gray model is the canonical statement of the main proposition the authors are interested in: that contract length is a decreasing function of real and monetary variability. My discussion will therefore focus first on the appropriateness of the empirical analysis in light of the Gray model, then on the limitations of the model as a way of understanding the data.

The essential point of Gray's theory is that both real and nominal uncertainty reduce optimal contract length. The model consists of the following equations for output, Y_t , money supply, M_t^s , and money demand, M_t^D , given labour, L_t , and price level, P_t , and shocks α and β to productivity and money supply, respectively:

$$\ln Y_t = \delta \ln L_t + \alpha_t \quad \text{var}(\alpha) = V_\alpha$$

$$\ln M_t^s = \bar{M} + \beta_t \quad \text{var}(\beta) = V_\beta$$

$$\ln M_t^D = \ln \kappa + \ln P_t + \ln Y_t.$$

Gray assumes that α , β follow independent Wiener processes.

Labour is supplied according to contracts that set wages, w , and indexation γ for l periods in the future; employment is determined by labour demand after the current shock is realized:

$$\ln L_t^D = -\eta(\ln w_t - \alpha_t) + \eta \ln \delta$$

$$\ln L_t^s = \varepsilon \ln w_t + \eta \ln \delta.$$

The price level adjusts each period to clear the money market. Note that in an equilibrium without wage rigidity, output would be given by $Y_t^s = \delta \ln L_t^s + \alpha$, where the labour quantity, L_t^s , represents full employment. Contract characteristics are chosen by a planner to minimize the loss function, which is assumed to be proportional to deviations from full-employment output:

$$\min_{l, \gamma} \left\{ \frac{\lambda}{l} \int_0^l E[\ln Y_t - \delta \ln L_t^s]^2 dt + C \right\}.$$

The solution of the model is an optimal indexation and an optimal contract length, (γ^*, l^*) , such that the following conditions hold:

$$\gamma^* = \theta + (1 - \theta) \frac{\varepsilon}{1 - \varepsilon}$$

$$l^* = \frac{\varepsilon + \eta}{\delta \eta^2} \phi,$$

where

$$\phi \equiv \left[\frac{2C/\lambda(V_\alpha \eta^2 + V_\beta)}{V_\alpha V_\beta} \right]$$

$$\theta \equiv \frac{V_\beta}{\frac{\eta^2(1 + \varepsilon)}{\varepsilon + \eta} V_\alpha + V_\beta}.$$

This solution implies that the optimal contract length is decreasing in the variance of the two types of shocks, and that the optimal indexation is a weighted sum of the optimal response to a monetary shock and the optimal response to a real shock. These are the properties at the heart of the Fay-Lavoie paper.

The paper's main strategy is to regress average contract length at a particular point in time on measures of the real and nominal uncertainty. In most cases, uncertainty is equated with variability, so the measure of uncertainty is a moving average of first differences. In addition, the authors present some results in which the dependent variable is the proportion of contracts with some positive level of indexing.

There are several reasons why this procedure is not the ideal way to implement the model, as the authors themselves recognize, but the choice of variables is driven by data constraints. The essential result, that real uncertainty does not seem to affect contract length, but nominal uncertainty does, confirms results by other researchers in the United States and Canada, and consequently one might hope that this indicates a robustness of the underlying relationship that is reflected indirectly through the proxy variables used in these and previous studies.

It seems to me that the mapping from the proxy variables to real and nominal uncertainty is somewhat hypothetical; how seriously should we believe that average variability reflects subjective uncertainty at a point in time? Is the duration of non-government labour contracts really representative of Canadian labour contracts, both explicit and implicit? Let us take the quality of the proxies for granted, however, and ask instead how to interpret the regression in light of the model.

A fairly direct empirical form of the model can be found by taking logs of the equation for optimal contract length:

$$\begin{aligned}\log l^* &= \log \left(\frac{\varepsilon + \eta}{\delta \eta^2} \right) + \log \phi \\ &= b_0 - \log V_\beta - \log V_\alpha + \log (V_\alpha \eta^2 + V_\beta).\end{aligned}$$

This corresponds fairly closely to the regression we see in the paper, except that we learn that the effect of uncertainty on contract length depends directly on another parameter that is not discussed: the wage elasticity of labour demand. The model assumes that this is constant over time, but it is clear that in real life, or in a more modern model, this is going to be determined by the profit-maximization problem of the firm. A deeper issue is that this equation assumes explicitly that the contract will have the optimal degree of wage indexation. Gray shows that if we allow the degree of indexation to deviate from the optimum, γ^* , the optimal contract length is decreasing in the size of the deviation. Since γ^* depends on both V_α and V_β , then the model tells us that variations in contract length may be due to failure of the contract process to arrive at the optimal degree of indexation.

In other words, the apparent failure of contract length to respond to reductions in real variability may be the result of constraints on indexation. Indeed, Fay and Lavoie's analysis of the data seems to suggest that contracts are trending towards zero indexation, which is not optimal as long as there is a positive probability of real shocks. Whether this trend to suboptimal indexation is related to the general weakening of labour unions in Canada is perhaps beyond the purview of the paper, but the trend to long-term

contracts without indexation seems to be a clear shifting of the burden of uncertainty from employers to workers, rather than the optimal response of the labour market under the Gray model to reduced monetary variability.

So far I have considered the model at face value. It is clear, however, that the model takes a very simplified view of the labour market, and it would be helpful to know whether labour contracts are in fact as rigid as Gray and the subsequent literature have construed them. In particular, the assumption of a fixed wage seems counterfactual; suppose instead that the wage depended on how many hours the worker was asked to supply. This seems to be the essence of overtime pay, and gives labour markets a way of responding to real shocks that improves upon the rigid wage contract.

Overall, the current empirical study is a valuable first step towards understanding the effect of changes in Canada's monetary policy. This paper demonstrates that regardless of the choice of proxy variables for real and nominal uncertainty, contract duration in Canada is negatively related to nominal uncertainty, and unrelated to real uncertainty. However, to establish that a less volatile monetary policy has indeed increased contract duration by reducing monetary uncertainty requires at the very least an explicit accounting for the prevalence of zero-indexing contracts. If, in addition, we believe that the wage elasticity of labour demand varies over time, possibly in response to the variability of these shocks, then a natural second step would be to estimate a dynamic model of equilibrium in the labour market, in which other changes experienced by the Canadian labour market are fully accounted for.

Reference

- Gray, J.A. 1978. "On Indexation and Contract Length." *Journal of Political Economy* 86 (1): 1-18.

General Discussion*

In their response to John Knowles, the authors said that to better understand and explore the forecast error issue, they would like to extend the data set prior to 1978. They acknowledged, however, that there would probably be difficulties in obtaining such data.

Participants also raised some issues regarding the nature of the data set. Specifically, Cédric Tille expressed concern about the exclusion of firms with less than 500 employees, who typically have contracts of shorter duration. Citing recent exchange rate pass-through literature, Tille also inquired if the data reflected a change in the sectoral "basket" towards sectors with longer contracts. Lawrence Schembri asked whether international data showed any increases in contract duration. He suggested that the data set be expanded to include the public sector.

The treatment of COLA¹ clauses was addressed by participants. Angelo Melino suggested that instead of a binary choice, COLA clauses should be measured as the degree of indexation within a contract. Gregor Smith suggested that an examination of the possible feedback between COLA clauses and contract duration might be necessary. Allen Head asked whether there was a link between contract duration and residual wage dispersion.

Michael Devereux warned against claiming welfare benefits stemming from longer contract duration in a world of sticky prices and improved monetary policy.

1. COLA: cost of living allowance.

* Prepared by Bill Laur and David Tulk.

Bob Fay and Sébastien Lavoie thanked the participants for their suggestions. They went on to point out that not only has there been little compositional change in the sectors over time, but the dynamics between small and large firms with respect to contract duration are very similar, and spillover effects are minimal. They noted, as well, that data from the United States show an increase in contract duration but not to the same extent as in Canada.

Section 3:
Price Adjustment
and Monetary Policy



How Do Canadian Hours Worked Respond to a Technology Shock?

*Lawrence J. Christiano, Martin Eichenbaum, and Robert Vigfusson**

Introduction

This paper investigates the response of hours worked to a permanent technology shock. Based on annual data from Canada and the United States, we argue that hours worked rises after a positive technology shock. While this result is consistent with the analysis in Christiano, Eichenbaum, and Vigfusson (CEV) (2003), it stands in sharp contrast to a large and growing literature, according to which hours worked falls after a positive technology shock (see, for example, Galí 1999 and Francis and Ramey 2001).¹

The assumption that we make to identify a technology shock is the same as in the literature. Specifically, we assume that the only type of shock that affects the long-run level of average labour productivity is a permanent shock to technology. So the difference between our results cannot be attributed to the nature of our identifying assumptions. Instead, it is due to the way hours worked is incorporated into our statistical analysis. Using quarterly U.S. time-series data, CEV (2003) make the following argument. Suppose that the analyst assumes that per capita hours worked is a stationary stochastic process and works with the level of hours. Using this "level specification," the analyst would find that hours worked in the United States rises after a technology shock. On the other hand, suppose that the analyst assumed that hours worked is a difference-stationary process and works with the growth rate of hours worked. Using this "difference specification,"

1. CEV (2003) base their analysis on quarterly U.S. time-series data.

* Lawrence Christiano and Martin Eichenbaum thank the National Science Foundation for financial assistance.

the analyst would find that hours worked in the United States falls after a technology shock. In this paper, we show that exactly the same result holds for annual Canadian and U.S. data.

The question is: Which set of results is correct—those based on the level specification or those based on the difference specification? Not surprisingly, standard, univariate hypothesis tests do not yield much information about whether per capita hours worked has a unit root or not. These tests cannot reject either the null hypothesis that per capita hours worked are difference-stationary or the null hypothesis that they are stationary. As in CEV (2003), we assess the relative plausibility of the two hypotheses and their associated implications by asking the following encompassing question: Which specification has an easier time explaining the findings that emerge when the analyst proceeds using the competing specification?

As discussed below and in CEV (2003), we expect that the specification that will do best on the encompassing criterion is the one that predicts that the other model is misspecified. These considerations lead us to think that the level specification will do better than the difference specification. This is because, if the level specification is true, an analyst who adopts the difference specification is committing a specification error. But, if the difference specification is true, an analyst who adopts the level specification is not committing a specification error. While important, this consideration is not definitive because sampling considerations also enter. Specifically, when the difference specification is true, then an econometrician who adopts the level specification will encounter a weak-instrument problem that implies large sampling uncertainty and bias in the estimates of the response of hours worked to a technology shock.

To choose between the level and difference specifications, we use the kind of posterior odds ratio considered in Christiano and Ljungqvist (1988) and CEV (2003). The preferred specification is the one that can most easily explain three facts: (i) the level specification implies that hours worked rises after a technology shock; (ii) the difference specification implies that hours worked falls; and (iii) the outcome of a weak-instrument test that we implement. Focusing only on facts (i) and (ii), we find that the odds are roughly two to one in favour of the level specification over the difference specification. However, once (iii) is incorporated into the analysis, we find that the odds overwhelmingly favour the level specification. Indeed, in the case of Canada, the odds in favour of the level specification are greater than nine to one.

After establishing the case for the level specification, we analyze how money growth, the interest rate, and inflation in Canada respond to a technology shock. Focusing on point estimates, we find that in response to such a shock, money growth rises while the interest rate and inflation drop. Sampling uncertainty aside, these findings suggest that Canadian monetary policy makers have accommodated technology shocks.

This raises a key question: Exactly what role has monetary policy played in the expansion of aggregate economic activity and the fall in inflation that follow in the wake of a positive technology shock? To answer this question requires that we know how the economy would have reacted had the monetary authority acted differently. The only place where we can perform such a counterfactual experiment is in a structural economic model. Such an analysis lies beyond the scope of this paper, which relies on reduced-form time-series methods. The methods used in this paper can deliver estimates of how monetary policy actually reacted to technology shocks. These methods, however, cannot be used directly to ask how the economy would have reacted under alternative policy rules.

For an analysis of that issue, we refer the reader to Altig, Christiano, Eichenbaum, and Linde (ACEL) (2003). Using an estimated dynamic general-equilibrium model embodying wage and price frictions, ACEL assess the response of the economy to a technology shock under alternative monetary policy rules, e.g., a k per cent growth-rate rule for money. Their key conclusion is that, had policy-makers not accommodated technology shocks, hours worked would have fallen for a prolonged period of time after a positive technology shock. Somewhat paradoxically, actual hours worked responds positively as in a real-business-cycle model, because of the systematic way monetary policy makers respond to technology shocks. Since ACEL (2003) estimate their model using U.S. data, we cannot claim that this result holds for Canada. But we suspect that it does.

The remainder of this paper is organized as follows. Section 1 discusses our strategy for identifying the effects of a permanent shock to technology. In section 2, we present the results from a bivariate analysis using data on hours worked and the growth rate of labour productivity. Section 3 discusses our encompassing strategy, the results of which are reported in section 4. In section 5, we report results for Canada and how inflation, the growth rate of money, and the interest rate respond to a technology shock. The final section contains concluding remarks.

1 Identifying the Response to a Permanent Technology Shock

In this section, we discuss how we identify the effect of a permanent shock to technology. As in Gali (1999); Gali, López-Salido, and Valles (2002); Francis and Ramey (2001); and CEV (2003), we assume that the only type of shock that affects the long-run level of average labour productivity is a permanent shock to technology.² As discussed in CEV (2003), this assumption is satisfied by a large class of standard business-cycle models. Still, it is important to recognize that there are models where this assumption is not satisfied.³

We estimate the dynamic effects of a technology shock using a variant of the Shapiro and Watson (1988) procedure for long-run identifying assumptions. Our description of this procedure borrows heavily from the relevant portion of CEV (2003). Our starting point is the relationship

$$\Delta f_t = \mu + \beta(L)\Delta f_{t-1} + \tilde{\alpha}(L)X_t + \varepsilon_t^z. \quad (1)$$

Here, f_t denotes the log of average labour productivity and $\tilde{\alpha}(L)$, $\beta(L)$ are polynomials of order q and $q-1$ in the lag operator, L , respectively. Also, Δ is the first-difference operator and we assume that Δf_t is covariance stationary. The white-noise random variable, ε_t^z , is the innovation to technology. Suppose that the response of X_t to an innovation in some non-technology shock, ε_t , is characterized by $X_t = \gamma(L)\varepsilon_t$, where $\gamma(L)$ is a polynomial in non-negative powers of L . We assume that each element of $\gamma(1)$ is non-zero. The assumption that non-technology shocks have no impact on f_t in the long run implies the following restriction on $\tilde{\alpha}(L)$:

$$\tilde{\alpha}(L) = \alpha(L)(1-L), \quad (2)$$

where $\alpha(L)$ is a polynomial of order $q-1$ in the lag operator. To see this, note first that the only way non-technology shocks can affect f_t is by their effect on X_t , while the long-run impact of a shock to ε_t on f_t is given by:

$$\frac{\tilde{\alpha}(1)\gamma(1)}{1-\beta(1)}.$$

2. There is now a large literature in which the long-run identifying assumption is adopted. See, for example, Vigfusson (2002); Altig, Christiano, Eichenbaum, and Linde (2003); and Fisher (2002).

3. For example, the assumption is not true in an endogenous growth model where *all* shocks affect productivity in the long run. Nor is it true in an otherwise standard model when there are permanent shocks to the tax rate on capital income.

The assumption that Δf_t is covariance stationary guarantees $|1 - \beta(1)| < \infty$. This, together with our assumption on $\gamma(L)$, implies that for the long-run impact of ϵ_t on f_t to be zero it must be that $\tilde{\alpha}(1)$ equals zero. This in turn is equivalent to equation (2).

Substituting equation (2) into equation (1) yields the relationship:

$$\Delta f_t = \mu + \beta(L)\Delta f_{t-1} + \alpha(L)\Delta X_t + \epsilon_t^z. \quad (3)$$

We obtain an estimate of ϵ_t^z by using equation (3) in conjunction with estimates of μ , $\beta(L)$ and $\alpha(L)$. If one of the shocks driving X_t is ϵ_t^z , then X_t and ϵ_t^z will be correlated. So, we cannot estimate the parameters in $\beta(L)$ and $\alpha(L)$ by ordinary least squares (OLS). Instead, we apply the standard instrumental-variables strategy used in the literature. In particular, we use as instruments a constant, Δf_{t-s} and X_{t-s} , $s = 1, 2, \dots, q$.

Given an estimate of the shocks in equation (3), we obtain an estimate of the dynamic response of f_t and X_t to ϵ_t^z , as follows. We begin by estimating the following q^{th} order vector autoregression (VAR):

$$Y_t = \alpha + B(L)Y_{t-1} + u_t, \quad Eu_t u_t' = V, \quad (4)$$

where

$$Y_t = \begin{pmatrix} \Delta f_t \\ X_t \end{pmatrix},$$

and u_t is the one-step-ahead forecast error in Y_t . Also, V is a positive-definite matrix. The parameters in this VAR, including V , can be estimated by OLS applied to each equation. In practice, we set q equal to 4. The fundamental economic shocks, e_t , are related to u_t by the following relation:

$$u_t = Ce_t, \quad Ee_t e_t' = I.$$

Without loss of generality, we suppose that ϵ_t^z is the first element of e_t . To compute the dynamic response of the variables in Y_t to ϵ_t^z , we require the first column of C . We obtain this by regressing u_t on ϵ_t^z by OLS. Finally, we simulate the dynamic response of Y_t to ϵ_t^z . For each lag in this response function, we computed the centred 95 per cent Bayesian confidence interval using the approach for just-identified systems discussed in Doan (1992).⁴

4. This approach requires drawing $B(L)$ and V repeatedly from their posterior distributions. Our results are based on 2,500 draws.

2 Empirical Results

A key issue when working with Canadian data is the limited span of the relevant quarterly data. Many studies of the effects of technology on the U.S. economy use quarterly data on Business Labor Productivity, a time series that is available starting in 1947. The analogous Canadian series starts only in 1987.⁵ Similarly, Canadian quarterly data on hours worked in the business sector are available starting in 1987.⁶ Since we are interested in identifying shocks that have a long-run effect on productivity, we work with annual data, which are available from 1961.⁷ Our measure of the Canadian population is for people between the ages of 15 and 64.⁸ We measured output as the average level of Canadian real GDP over the year.⁹ GDP is a broader measure of output than the measure considered in Francis and Ramey (2002) or CEV (2003), namely private sector output. Using a broader measure, however, seems reasonable given that we also use a broader measure of hours worked.

We are interested in comparing the effects of a technology shock in Canada and the United States. The U.S. data that we use are the annual version of the data used in CEV (2003). The relevant series are business labour productivity and hours.¹⁰ Our data on labour productivity growth and per capita hours worked in the United States and Canada are displayed in the first row of Figure 1 and Figure 2, respectively. For the United States, the average growth rate of these variables are -0.04 and 2.19 per cent, respectively. For Canada, the average growth rate of per capita hours and labour productivity is -0.03 and 1.80 per cent, respectively. The other variables in Figure 2 will be discussed in the multivariate section.

2.1 Impulse responses

We first consider results for a bivariate VAR for Y_t . The first element in Y_t is the growth rate of the log of labour productivity, f_t . The second element in Y_t is the log of per capita hours worked, h_t . Figure 3 reports the response of labour productivity and average hours to a one standard deviation long-

5. The CANSIM mnemonic for Business Sector Labor Productivity is V1409153.

6. The CANSIM series V1409155 measures quarterly hours worked in the business sector but starts only in 1987. The CANSIM series V159660 measures total hours worked in all sectors and is monthly but starts only in 1976.

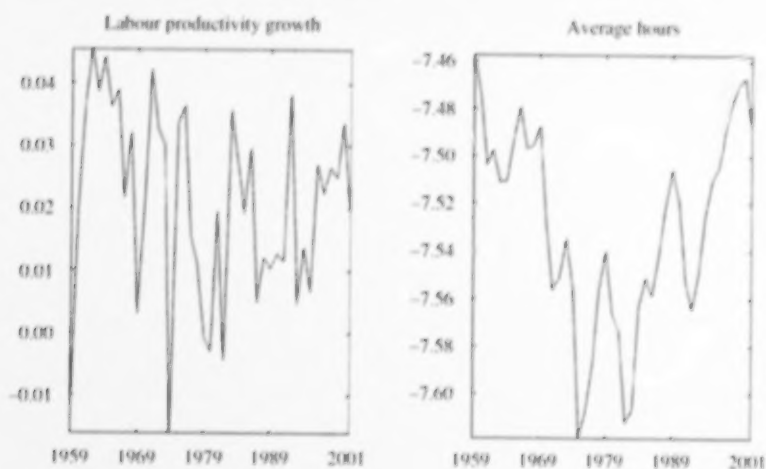
7. Annual total hours worked is measured using the CANSIM series V719842.

8. Data on this population measure are available from 1971 as CANSIM series V466971. We construct population data for the 1960s using the growth rate of the population aged 14 and over from the Canadian Historical Statistics.

9. Real GDP is measured using CANSIM series V1992067.

10. These series have DRI Economics mnemonic LBOUT and LBMN, respectively.

Figure 1
Data used in VAR, United States



run technology shock. In the United States, both labour productivity and average hours rise by roughly 1 per cent in the first year of the shock. Labour productivity continues to rise for the next eight years. Hours worked rises in a hump-shaped pattern, reaching a peak response of almost 2 per cent two years after a positive technology shock. Hours, then, slowly returns to the pre-shock level. Using Canadian data, we find similar results. In the year of the shock, labour productivity and hours worked both rise. Labour productivity rises by roughly 1 per cent while average hours rises by 0.4 per cent. The maximal rise in hours worked, 0.8 per cent, occurs a year after the shock. In Canada, it takes roughly six years for hours worked to return to its pre-shock level. For both countries, the rise in average productivity is statistically significant for a prolonged period of time. In contrast, confidence intervals about the estimated impulse-response functions for hours worked are wide. Still, the rise in U.S. hours worked is statistically different from zero for the first three years after the shock. For Canada, the rise in hours worked is statistically different from zero only in the first year after the shock.

As with the benchmark results in CEV (2003), our findings stand in sharp contrast to the literature, according to which hours worked in the United States falls after a positive technology shock (see, for example, Galf 1999 and Francis and Ramey 2001). But what accounts for this difference? It cannot be attributed to our identifying assumptions, since these are the same

Figure 2
Data used in VAR, Canada

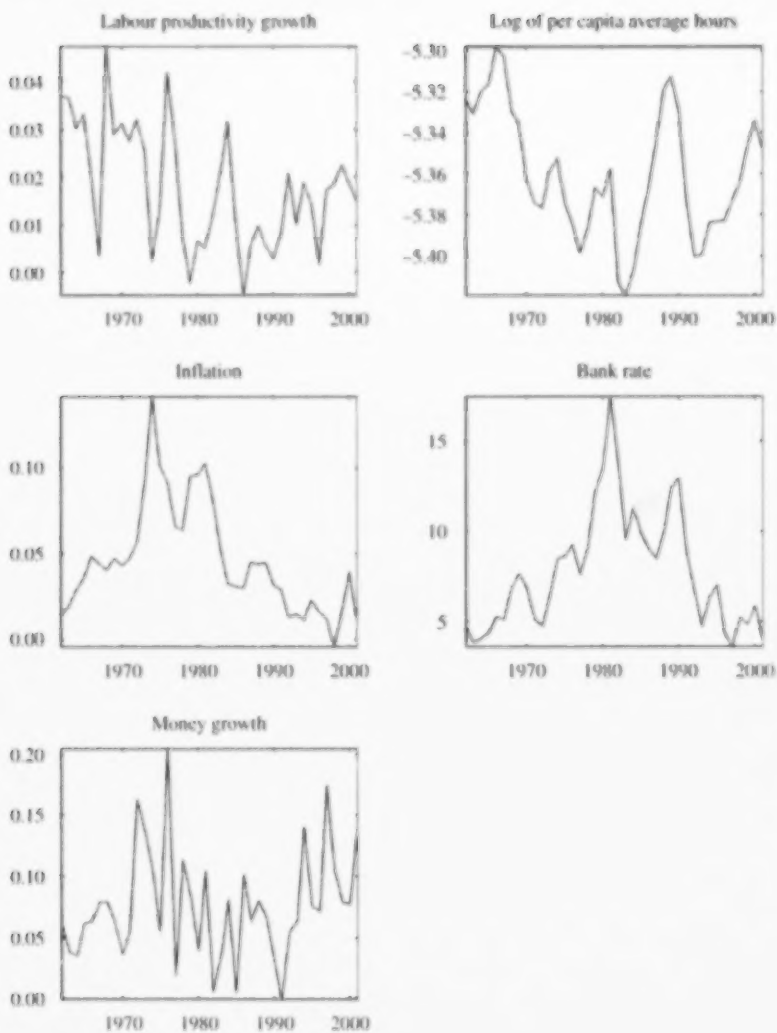
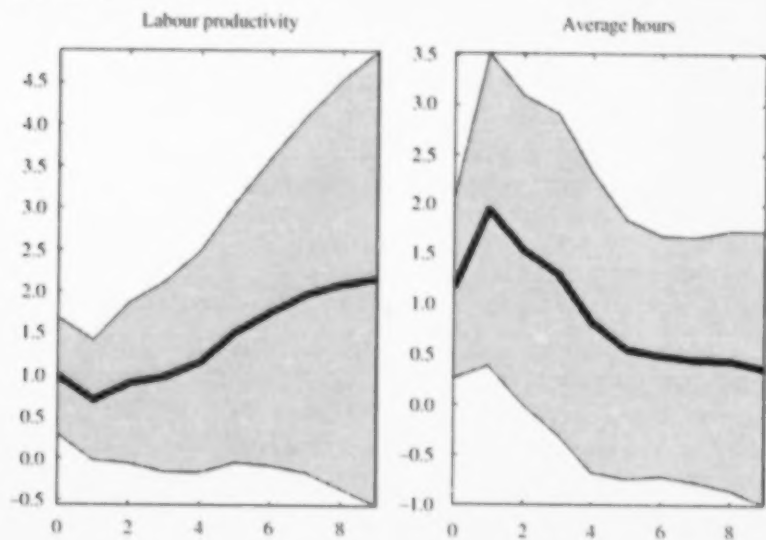
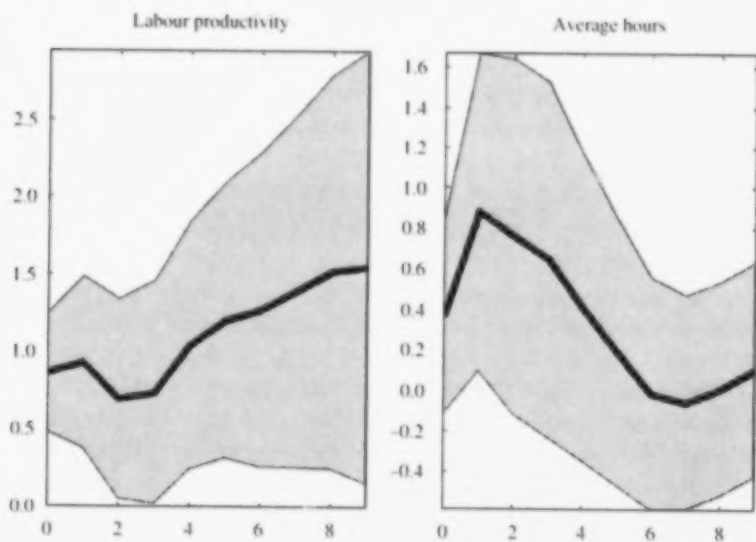


Figure 3
Impulse responses using the level specification

Panel A: United States



Panel B: Canada



Thick line: Impulse responses from level specification.
Grey area: 95 per cent confidence intervals.

as in the literature. Using quarterly U.S. data, CEV (2003) argue that the key difference has to do with how hours worked is incorporated into the analysis. There, we show that when we include Δh_t in Y_t , then hours worked falls after a technology shock. In contrast, when we include h_t in Y_t , then hours worked rises after a technology shock. For future reference, we refer to the specification when h_t is included in Y_t as the *level specification*. We refer to the specification when Δh_t is included in Y_t as the *difference specification*.

We find similar results for the annual Canadian and U.S. data. Specifically, suppose that X_t in equations (1) and (3) corresponds to the growth rate of hours worked rather than to the level of hours worked. Figure 4 reports our results for the United States and Canada. In both countries, a positive technology shock leads to a sharp, prolonged rise in labour productivity. In contrast to the results above, we now find that hours worked falls after a positive technology shock. Indeed, in both countries, according to our point estimates, hours worked never returns to the pre-shock level. Granted, confidence intervals are very large. But at least for the United States, CEV (2003) show that the initial fall in hours worked is statistically significant when the effect of a technology shock is estimated using quarterly data.

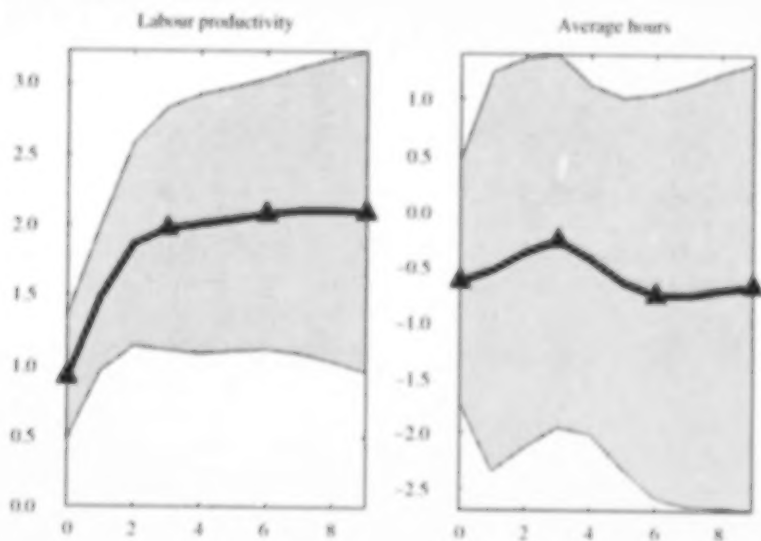
In sum, when we work with the level specification, a positive technology shock induces a large temporary increase in hours worked, both in Canada and the United States. But when we work with difference specification, a positive technology shock leads to a persistent decline in hours worked. In the next section, we address the question: Which of the competing results are more plausible, those based on the level specification or those based on the difference specification?

3 Choosing Between the Two Specifications

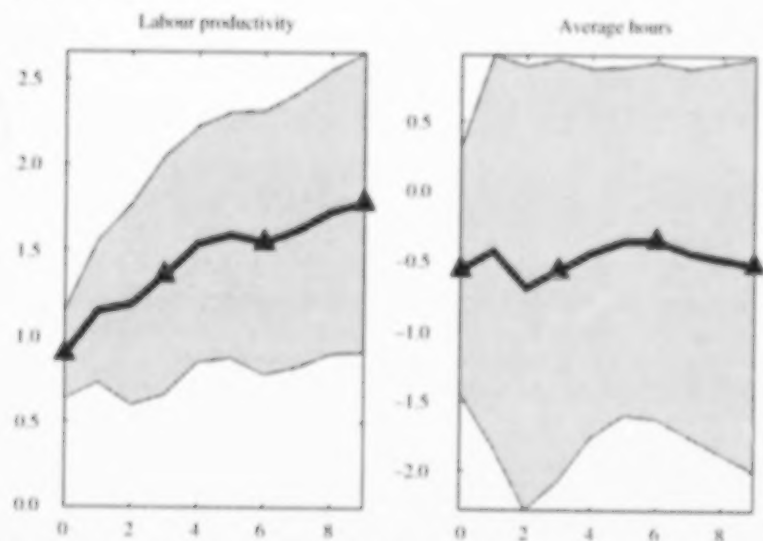
The level and difference specifications are based on different statistical models, corresponding to whether we assume that hours worked is difference-stationary or stationary in levels. As we saw, these specifications generated different answers to the question of what happens to hours worked after a positive technology shock. To assess which answer is more plausible, we must select between the statistical models underlying the two specifications. We first address this issue using standard classical diagnostic tests. Since these do not convincingly discriminate between the competing specifications, we then turn to the type of encompassing methods employed in CEV (2003).

Figure 4
Impulse responses using the level specification

Panel A: United States



Panel B: Canada



Line with triangles: Impulse responses from difference specification.

Grey area: 95 per cent confidence intervals for simulated impulse responses.

3.1 Tests for unit roots and stationarity

In this subsection, we report the results for two well-known statistical tests of whether a univariate time series has a unit root. The first test is the augmented Dickey-Fuller (ADF) test, which tests the null hypothesis that hours worked has a unit root. The second test is the KPSS test (from Kwiatkowski et al. 1992), which tests the null hypothesis that hours worked is stationary. For the United States hour series, the ADF test fails to reject, at the 10 per cent significance level, the null hypothesis that per capita hours worked has a unit root.¹¹ At the same time, the KPSS test fails to reject the null hypothesis, at the 10 per cent significance level, that per capita hours worked is stationary.¹² For Canada, the results are somewhat more supportive of the level specification. The ADF test rejects the unit-root hypothesis at the 2.5 per cent significance level but fails to reject it at the 1 per cent level.¹³ The KPSS test fails to reject the null hypothesis of stationarity at the 5 per cent significance level.¹⁴ Based on these results, we conclude that conventional standard classical diagnostic tests cannot be used to convincingly discriminate between our two competing statistical models of per capita hours worked, either in Canada or the United States.

3.2 Encompassing tests

In the preceding section, we showed that conventional classical methods are not useful for selecting between the level and difference specifications of our VAR. An alternative way to select between the competing specifications is to use an encompassing criterion. Under this criterion, a model must not just be defensible on standard classical diagnostic grounds. It must also be able to predict the results based on the opposing model. If one of the two views fails this encompassing test, the one that passes is to be preferred.

In what follows, we review the impact of specification error and sampling uncertainty on the ability of each specification to encompass the other. Our

11. The ADF test statistic (with two lags) equals -1.6014. The critical value corresponding to a 10 per cent significance level is -2.57.

12. The value of the KPSS test statistic is 0.3221. The asymptotic critical value at the 10 per cent significance level is 0.347. In implementing this test, we set the number of lags in our Newey-West estimator of the relevant covariance matrix to two.

13. The ADF test statistic has a value of -2.5768 with three lags, while the small sample critical values are -2.26 and -2.66 at the 10 per cent and 5 per cent significance level, respectively. Asymptotic critical values for the ADF test statistic are -2.23 and -2.58 at the 10 per cent and 5 per cent significance level, respectively.

14. With two lags, the KPSS test statistic has a value of 0.3577. Therefore, one would not reject the null at the 5 per cent significance level using the asymptotic critical value of 0.463.

discussion here closely parallels the analysis in CEV (2003), who argue that, other things being equal, the specification that will do best on the encompassing test is the one that predicts that the other specification is misspecified.

We show in the next section that the level specification predicts that the difference specification is misspecified. We therefore expect that the level specification will do better than the difference specification. But as noted in CEV (2003), this consideration is not definitive because sampling considerations also enter. After discussing these issues, we present our bivariate encompassing results.

3.2.1 *A priori considerations when the level specification is true*

If the level specification is true and the econometrician adopts the difference specification, he is committing a specification error. To see why, recall the two steps involved in estimating the dynamic response of a variable to a technology shock. The first involves the instrumental-variables equation used to estimate the technology shock itself. The second involves the VAR used to obtain the actual impulse responses.

Suppose the econometrician estimates the instrumental-variables equation under the mistaken assumption that hours worked is a difference-stationary variable. In addition, assume that the only variable in X_t is log hours worked. The econometrician would difference X_t twice and estimate μ along with the coefficients in the finite-ordered polynomials, $\beta(L)$ and $\alpha(L)$, in the system:

$$\Delta f_t = \mu + \beta(L)\Delta f_{t-1} + \alpha(L)(1-L)\Delta X_t + e_t^f.$$

Suppose that X_t has not been over-differenced, so that its spectral density is different from zero at frequency zero. Then, in the true relationship, the term involving X_t is actually $\bar{\alpha}(L)\Delta X_t$, where $\bar{\alpha}(L)$ is a finite ordered polynomial. In this case, the econometrician commits a specification error because the parameter space does not include the true parameter values. The only way $\alpha(L)(1-L)$ could ever be equal to $\bar{\alpha}(L)$ is if $\alpha(L)$ has a unit pole, i.e., if $\alpha(L) = \bar{\alpha}(L)/(1-L)$. This is impossible, however, since no finite lag polynomial, $\alpha(L)$, has this property. So, incorrectly assuming that X_t has a unit root entails specification error.

We now turn to the VAR used to estimate the response to a shock. A stationary series that is first differenced has a unit moving average root. It is well known that there does not exist a finite-lag vector autoregressive

representation of such a process. So here too, proceeding as though the data are difference-stationary entails a specification error.

3.2.2 *A priori considerations when the difference specification is true*

Suppose the difference specification is true but the econometrician works with the level specification. Here, the econometrician is not committing a specification error. To see this, first consider the instrumental-variables regression:

$$\Delta f_t = \mu + \beta(L)\Delta f_{t-1} + \alpha(L)\Delta X_t + \varepsilon_t^z, \quad (5)$$

where the polynomials, $\beta(L)$ and $\alpha(L)$, are of order q and $q-1$, respectively. The econometrician does not impose the restriction $\alpha(1)$ equals zero when it is, in fact, true. This is not a specification error, because the parameter space does not rule out $\alpha(1)$ equal to zero. In estimating the VAR, the econometrician also does not impose the restriction that hours worked is difference-stationary. This also does not constitute a specification error, because the level VAR allows for a unit root (see Sims, Stock, and Watson 1990).

The fact that the econometrician is not committing a specification error does not necessarily imply that the level specification can encompass the difference results. This is because sampling considerations must be taken into account. CEV (2003) stress that the difference specification implies that the level specification suffers from a weak-instrument problem. Weak instruments can lead to large sampling uncertainty, as well as bias. These considerations may help the difference specification explain the results of the level specification.

To see why a weak instrument arises, recall that the econometrician who adopts the level specification uses lagged values of X_t as instruments for ΔX_t . If X_t , however, actually has a unit root, this results in a weak-instrument problem. Lagged X_t 's are poor instruments for ΔX_t , because ΔX_t is driven by relatively recent shocks, while X_t is heavily influenced by shocks that occurred long ago. At least in large samples there is little information in lagged X_t 's for ΔX_t .

A different way to see why a weak-instrument problem arises when the econometrician mistakenly adopts the level specification is as follows. Consider the regression

$$\Delta h_t = a + \Pi h_{t-1} + p(L)\Delta h_{t-1} + q(L)\Delta f_{t-1} + \varepsilon_t^z. \quad (6)$$

A test of the hypothesis that Π is equal to zero has two interpretations. First, it is the cointegration ADF test of Hansen (1995) for whether h_t has a unit root ($\Pi = 0$). Second, it is the standard F -test for weak instruments discussed in Staiger and Stock (1997) for whether the lagged level of hours is a weak instrument for Δh_t ($\Pi = 0$). So here, testing for the presence of a unit root in h_t is the same as testing for whether lagged hours is a weak instrument for the Δh_t . If the difference specification is true, then at least asymptotically one could not reject either hypothesis.

To summarize, when the level specification is true, the difference specification is misspecified. When the difference specification is true, the level specification is not misspecified, but the econometrician will encounter a weak-instrument problem and there will likely be large sampling uncertainty, as well as bias, associated with parameter estimates.

4 Encompassing Results

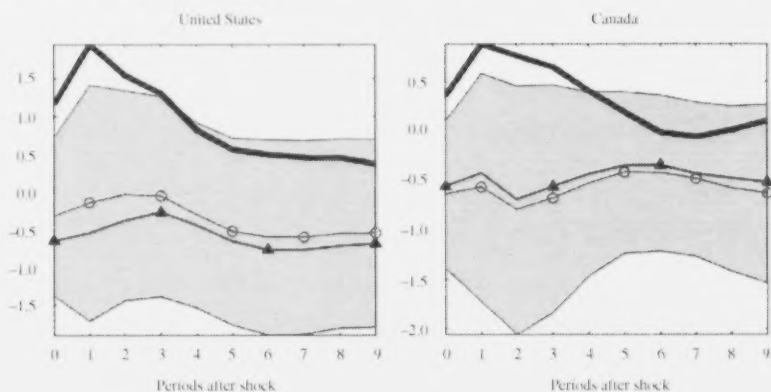
We base our encompassing tests on the ability of the level and difference specifications to match three observations. The first two observations come from the empirical-hours response that arises from the two different specifications. For the level specification, the average-hours response following a technology shock is positive. For the difference specification, the average-hours response is negative. The encompassing test compares the ability of each specification to account for both of these findings. The third observation is the empirical value of the weak instrument F -test. Specifically, we assess the ability of the level and difference specification to account for the observed F -test (equation 6). If the level specification is true then the lagged level of hours will be a good instrument. If the difference specification is true, then the lagged level of hours will be a poor instrument. Therefore, the two specifications ought to have different implications for the weak-instrument F -test.

4.1 Does the level specification encompass the difference specification results?

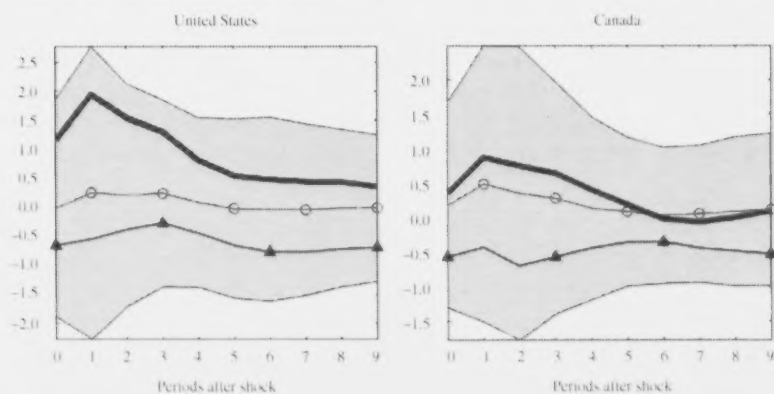
To determine whether the level specification can encompass the difference specification, we proceed as in CEV (2003). For each country, we use the estimated level specification VAR as the data-generating process (DGP). With this DGP, we simulate by bootstrap 1,000 artificial data sets, each of length equal to our actual sample size. For each simulated data set, we then (incorrectly) assume that the difference specification is true, and estimate a bivariate VAR in which hours worked appears in growth rates, and compute the impulse responses to a technology shock. Panel A of Figure 5 reports the

Figure 5
Encompassing results

Panel A: Level specification as the DGP



Panel B: Growth rate specification as the DGP



Thick line: Impulse responses from level specification.

Line with triangles: Impulse responses from difference specification.

Line with circles: Average impulse response for simulations from designated DGP.

Grey area: 95 per cent confidence intervals for simulated impulse responses.

distribution of impulse responses that arise from the simulation. The mean impulse responses appear as the thin line with circles. They correspond to the prediction of the level specification for the impulse responses that one would obtain with the (misspecified) difference specification. The lines with triangles are reproduced from Figure 4 and correspond to our point estimate of the relevant impulse-response function generated from the difference specification. The thick lines are reproduced from Figure 3 and correspond to the point estimate of the relevant impulse-response function generated from the level specification. The gray area represents the 95 per cent confidence interval of the simulated impulse-response functions.¹⁵

From Figure 5, we see that, for both countries, the average of the impulse-response functions emerging from the "misspecified" growth rate VAR is very close to the actual estimated impulse response generated using the difference specification. In particular, hours worked are predicted to *fall* after a positive technology shock even though they *rise* in the actual DGP. Evidently, the specification error associated with incorrectly adopting the difference specification can explain the estimated fall in hours found using the difference specification. In other words, the level specification attributes the decline in hours in the estimated VAR with differenced hours to over-differencing. We conclude that the level specification convincingly encompasses the difference specification.

4.2 Does the difference specification encompass the level results?

To assess the ability of the difference specification to encompass the level specification, we proceed as above except we now take as the DGP the estimated VARs in which hours worked appears in growth rates. Panel B in Figure 5 reports results analogous to those in Panel A. The thick solid lines, reproduced from Figure 3, are the impulse responses associated with the estimated level specification. The thin lines with the triangles are reproduced from Figure 4 and are the impulse responses associated with the difference specification.

The thin lines with circles in Panel B are the mean impulse-response functions that result from estimating the level specification of the VAR using the artificial data. They represent the difference specification's prediction for the impulse responses that one would obtain with the level specification. The grey area represents the 95 per cent confidence interval of the simulated impulse-response functions.

15. Confidence intervals were computed point-wise as the average simulated response plus or minus 1.96 times the standard deviation of the simulated responses.

Two results are worth noting. First, for the United States, the hours response is nearly zero. This result is closer to the difference specification than the level specification and therefore suggests that the distortion associated with not imposing a unit root in hours worked is not very large. The Canadian data have results that are somewhat different. Here the mean impulse response for hours is actually close to the level specification's result.¹⁶ In part, this reflects the small sample-bias issues discussed in CEV (2003). Apparently, given the small sample of Canadian data, the level specification has some difficulty recovering the true impulse responses. Consistent with this, there is a great deal of sampling uncertainty associated with the estimated impulse-response function. Indeed, the confidence intervals in Panel B of Figure 5 are substantially much wider than those reported in the other figures.

Recall from our discussion above that if the difference specification is true, then an econometrician who works with the level specification ought to encounter large sampling uncertainty. This prediction faces a basic problem: It rests fundamentally on the difference specification's implication that there is a weak-instrument problem. But as we show below, when we apply a standard test for weak instruments to the data, we find little evidence of this problem. Moreover, the actual estimated confidence intervals associated with impulse responses obtained using the level specification are relatively narrow (see Figure 3).

4.3 Testing for weak instruments

To assess whether there is evidence of weak instruments in the data, we use a standard F -test for weak instruments. Specifically, we regressed ΔH_t on a constant, H_{t-1} , and the predetermined variables in the instrumental-variables regression, equation (5). These are ΔH_{t-s} and Δf_{t-s} , $s = 1, 2, 3$. Our weak-instrument F -statistic is the square of the t -statistic associated with the coefficient on H_{t-1} . In effect, this F -statistic measures the incremental information in H_{t-1} about ΔH_t .¹⁷ If the difference specification is correct, the additional information is zero.

For the United States, the weak-instrument F -test is 5.95. This is below Staiger's and Stock recommended threshold value of 10, which suggests that, for the U.S. data, there may be a weak-instrument problem. In contrast,

16. These results are somewhat different than those reported for the quarterly U.S. data in CEV (2003).

17. As noted above, our F -test is equivalent to a standard ADF test with additional regressors. In the unit-root literature, this test is referred to as the covariate ADF test (Hansen 1995).

CEV (2003) report that there is little evidence of this problem with the U.S. quarterly data. For Canada, the weak-instrument F -test is 11.60, which suggests that there is no weak-instrument problem with the Canadian data.¹⁸ As discussed above, this calls into question a basic implication of the view that hours worked has a unit root.

4.4 The relative odds of the two specifications

The results of the previous subsections indicate that the level specification can easily account for the estimated impulse-response functions obtained with the difference specification. The difference specification has a somewhat harder time accounting for the level specification results. As in CEV (2003), we quantify the relative plausibility of the two specifications by using the type of posterior odds ratio considered in Christiano and Ljungqvist (1988). Christiano and Ljungqvist developed their statistic for a similar situation where differences and levels of data lead to very different inferences.¹⁹ In our context, we claim that the more plausible of the two VARs is the one that has the easiest time explaining the facts: (i) the level specification implies that hours worked rises after a technology shock; (ii) the difference specification implies that hours worked falls; and (iii) the value of the weak-instrument F -statistic.

The odds ratio that we use is calculated as follows. We simulated 1,000 artificial data sets using each of our two estimated VARs as the DGP. For an event Q , we asked what was the probability of observing that event for the level specification, $P(Q|A)$, where A denotes the level specification being true, and what was the probability of observing that event for the difference specification, $P(Q|B)$, where B denotes the difference specification being true. The relative plausibility of the two different specifications can then be assessed as the odds ratio of the level specification being true versus the difference specification being true given the observed event

18. The evidence against the difference specification reported here is stronger than we obtained using the ADF test in section 3.1. This is consistent with the analysis of Hansen (1995) and Elliott and Jansson (2003), who show that incorporating additional variables into unit-root tests can dramatically raise their power.

19. Eichenbaum and Singleton (1986) found in a VAR analysis that when they worked with first differences of variables, there was little evidence that monetary policy plays an important role in business cycles. However, when they worked with a trend stationary specification, monetary policy seems to play an important role in business cycles. Christiano and Ljungqvist argued that the preponderance of the evidence supported the trend stationary specification.

$$\frac{P(A|Q)}{P(B|Q)} = \frac{P(Q|A)P(A)}{P(Q|B)P(B)}.$$

If one had a prior distribution that put equal weight on A and B , then the odds ratio is just the ratio of the conditional probabilities

$$\frac{P(Q|A)}{P(Q|B)}.$$

We consider five definitions of the event Q :

- (i) the difference specification is true, and the impact effect of a technology shock on hours worked is negative;
- (ii) the level specification is true, and the impact effect of a technology shock on hours worked is positive;
- (iii) both (i) and (ii) are true;
- (iv) the weak instrument F -statistic test is greater than or equal to the F -statistic obtained with the actual data;
- (v) events (i), (ii), and (iv) occur.

Table 1 reports the frequency with which the different events were observed in the two simulated data sets. For the U.S. case, the difference specification does slightly better at predicting event (i). But the level specification does much better at predicting events (ii) and (iv). The overall plausibility of the two specifications can be most easily assessed in terms of event (v), in which case, the odds ratio favours the level specification by over five to one. Similar results hold for the Canadian case. Surprisingly, the fall in hours associated with the difference specification is actually observed more frequently when the DGP corresponds to the level specification. Focusing on event (v), the odds ratio favours the level specification by over nine to one. So the odds in favour of the level specification are even higher for the Canadian case than for the U.S. case. This is consistent with our F -test results indicating less of a weak-instrument problem for Canada than for the United States.

5 Multivariate Results for Canada

In this section, we discuss how other Canadian variables (money growth, inflation, and the interest rate) respond to a technology shock.²⁰ To estimate these response functions, one could proceed as in CEV (2003) and estimate

20. See CEV (2003) and ACEL (2003) for multivariate results based on quarterly U.S. data.

Table 1
Simulations results and odds ratios

		United States			Canada		
		Percentage true		Odds	Percentage true		Odds
Specification	*	Level	Difference		Level	Difference	
Event							
(i)	Impact negative, difference specification	67.7	71.4	0.949	91.6	81.1	1.130
(ii)	Impact positive, level specification	97.1	54.3	1.788	96.9	66.8	1.451
(iii)	Both impact responses	65.6	37.3	1.757	88.5	53.3	1.660
(iv)	<i>F</i> -test	70.1	22.9	3.066	65.0	10.7	6.070
(v)	Events (i), (iii), and (iv) true	47.6	8.9	5.343	57.6	6.2	9.290

the large simultaneous system. However, given our small sample size and the large number of parameters that would have to be estimated, we are reluctant to do so. For example, a five-variable VAR with four lags requires estimating 110 coefficients with only 40 years worth of annual data. Instead, we adopt the following sequential approach. Suppose we are interested in estimating the dynamic response functions of a set of variables, $X_1, X_2, X_3, \dots$. For a given variable, X_i , we estimate the technology shocks $\varepsilon_t^{z,i}$ using the following version of our basic IV equation:

$$\Delta f_t = \mu + \beta(L)\Delta f_{t-1} + \alpha_H(L)\Delta H_t + \alpha_{X_i}(L)\Delta X_{it} + \varepsilon_t^{z,i}. \quad (7)$$

We then estimate the VAR,

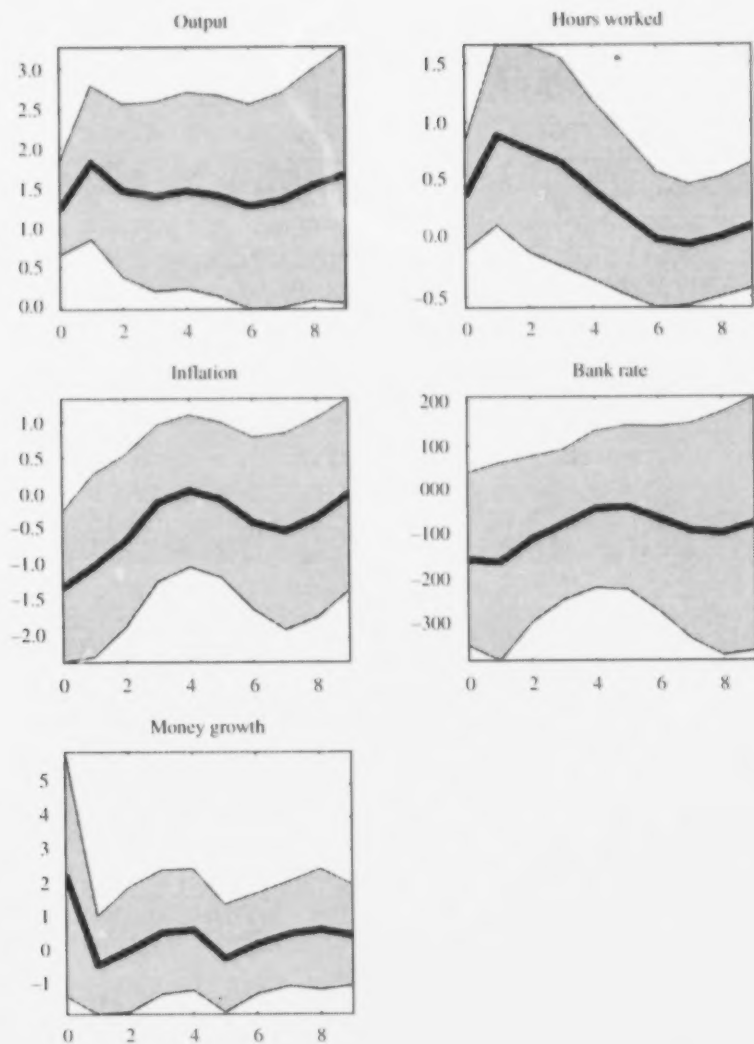
$$\begin{pmatrix} \Delta f_t \\ H_t \\ X_{it} \end{pmatrix} = B(L) \begin{pmatrix} \Delta f_{t-1} \\ H_{t-1} \\ X_{it-1} \end{pmatrix} + \gamma \varepsilon_t^{z,i} + v_t.$$

Finally, we derive the impulse response of X_{it} to a technology shock from the estimated VAR. Given the results of the previous section, we confine our attention to the level specification.

Figure 2 displays the time series on Canadian money growth, inflation, and the interest rate.²¹ Figure 6 reports the estimated response of these variables to a technology shock. For convenience, the hours responses are repeated

21. The Bank Rate is measured using CANSIM series B14006. The money supply is M2, with CANSIM mnemonic B1630. Inflation is measured as the growth rate of the GDP deflator D15612.

Figure 6
Sequential analysis



Thick line: Impulse responses from level specification.
Grey area: 95 per cent confidence intervals for simulated impulse responses.

from Figure 3 as well as the output response implied by the bivariate VAR reported in Figure 3. Two key results emerge here. First, our point estimates indicate that inflation and the interest rate fall after an expansionary technology shock, while money growth rises. This suggests that the Bank of Canada accommodated technology shocks over our sample period. Second, the confidence intervals around the estimated impulse-response functions are quite wide. Still, the initial fall in inflation is statistically significant.²²

Conclusions

Using annual Canadian and U.S. data, this paper argues that a positive technology shock leads to a rise in Canadian output and hours worked, as well as a fall in inflation. In CEV (2003), using similar methods and quarterly U.S. data, we argued that a technology shock also leads to a rise in aggregate consumption and investment. On the face of it, these findings are consistent with the predictions of a real-business-cycle model. But, in our view, the rise in hours worked and overall expansion in aggregate activity that follows in the wake of a technology shock reflect how monetary policy makers reacted to the technology shock. While our empirical results are suggestive on this point, they are not definitive. To make the case convincingly requires that we know how the economy would have reacted had the monetary authority acted differently. The only place where we can perform such a counterfactual experiment is in a structural economic model.

ACEL (2003) conduct this type of experiment in a dynamic general-equilibrium model embodying wage and price frictions. They argue that an estimated version of the model can account for how the U.S. economy reacted to monetary policy and technology shocks in the post-war era. They use this model as a laboratory to investigate how the U.S. economy would have reacted to a technology shock with a different monetary policy. For example, they consider what would have happened under the assumption that the Federal Reserve had not accommodated technology shocks but rather had followed a k per cent money-growth rule. The key conclusion in ACEL is that, with this counterfactual policy, hours worked would have *fallen* for a prolonged period of time after a positive technology shock. In addition, compared to the actual outcomes, output would have risen by far less and inflation would have fallen by far more. We suspect that the same result would be true for Canada. Based on these results and similar findings in Gali, López-Salido, and Valles (2003), it is clear that policy-makers ought to be vitally interested in the supply-side developments of the economy.

22. Note that the confidence intervals become extremely wide in the long run. This may reflect a near unit root in our measure of the Canadian interest rate.

Simple formulations of policy, like Taylor rules, often push discussions of the output gap into the background. Knowing why the gap moves is a critical input into policy decisions. Taken together, the results of this paper, CEV (2003) and ACEL (2003), suggest that policy-makers have, in fact, been successful at identifying technology shocks and have reacted in a way that has improved aggregate economic performance.

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Discussion

Kevin Moran

Context and Summary

The task of discussing this paper was an occasion for me to learn about the debate over the effects of technology shocks on hours, in particular, and recent advances on the connection between empirical and quantitative-theoretic models, in general. I am grateful to the authors and to the conference organizers for this opportunity.

One of the research programs pursued by the authors is estimating dynamic stochastic general-equilibrium (DSGE) models by minimizing the distance between two sets of impulse responses: those implied by the model and those retrieved from data. The success of this strategy thus rests largely on the quality of the impulse responses derived from the data. There is already a voluminous literature documenting the shape of the impulse responses that follow a monetary policy shock, and these have been used to estimate DSGE models with real and nominal rigidities (see Christiano, Eichenbaum, and Evans 2001). The underlying research objective motivating the work contained in the present paper is to identify data-derived impulse responses from technology shocks and propose them as the next targets that the estimation of DGE models should try to match.

The specific contribution of the paper is to shed light on the shape of the impulse responses that follow technology shocks. This has been a topic of brisk controversy since Galí (1999) proposed an econometric procedure to identify technology shocks and, among other results, reported that hours worked appeared to decrease following persistent, positive technology shocks. Such a result is important because sticky-price models can generate it fairly easily, while standard real-business-cycle models will most likely generate the opposite result, i.e., an increase in hours. An estimation method

that seeks to make the model consistent with these responses would therefore probably favour the sticky-price model.

The paper uses annual data from Canada and the United States, thus providing a comparison with parallel research that used quarterly American data (Christiano, Eichenbaum, and Vigfusson 2003). Using Gali's procedure, the authors first show that his result does not appear to be robust to the assumption regarding the stationarity of hours. When hours are treated as difference-stationary (as was the situation in Gali's benchmark case) and consequently the growth rates of hours are used in the empirical work, Gali's result obtains: hours fall following a favourable technology shock. However, if one views hours as stationary and therefore levels are used, Gali's results are reversed: hours now increase following the technology shock. Second, the authors repeat their analysis using a simulated data set, where technology shocks increase hours *by construction*. They find that assuming difference-stationarity leads to the incorrect conclusion that hours fall. This casts doubt on the ability of the difference-stationary specification to recognize any positive correlation between hours and technology shocks. Third, the authors extend their analysis to a multivariate system in which the interest rate, inflation, and money growth are added as macroeconomic variables of interest. They report that the responses using the Canadian data are consistent with the view that the Bank of Canada accommodates technology shocks. The authors conclude that technology shocks are associated with an increase—rather than a decrease—in hours, even if the contribution of these shocks to business cycles is not as strong as once thought.

1 How to (Statistically) Treat Hours

Gali (1999) identifies technology shocks by assuming they are the only source of permanent fluctuation in measures of average labour productivity, within a bivariate vector autoregression (VAR) containing hours and the productivity variable.¹ The authors confirm that when the measure of hours worked is first-differenced (Gali's benchmark case), the procedure produces a negative response of hours worked following a favourable technology shock. However, when using the level of (per-capita) hours, or a (linearly)

1. The strategy of using long-run restrictions to identify shocks in VARs originates in Blanchard and Quah (1989), where the authors identify supply shocks by assuming that within a bivariate (output, unemployment) VAR, such shocks are the only ones having a permanent effect on output. Interestingly, Blanchard and Quah report that following a favourable supply shock, unemployment initially increases before eventually decreasing, a result that can be interpreted as consistent with Gali's.

detrended version of these levels, they report that a positive technology shock is associated with an increase in hours.

My first comment concerns the possibility that the correct statistical representation of hours may be in the form of a trend-stationary process. Galí (1999) reports, within a series of checks on the robustness of his results, that the negative correlation between hours and technology shocks is still present when hours are detrended linearly (see Galí 1999, Figure 3). While confirming these results, the authors (2003) argue that the correlation is dependent on the specific manner in which the trend is introduced and, furthermore, that there is no conclusive evidence that the trend-stationary assumption is the correct way to describe the available data. It would be interesting to verify what kind of trend, if any, is appropriate for Canadian data and what the implications are of using detrended hours for the results presented here.²

Second, we know that the effect of the first-difference filter is to over-emphasize the high-frequency components of the series to which it is applied (i.e., the gain of that filter increases significantly as the frequency increases; see Baxter and King 1999, Figure 5). This suggests that both negative and positive correlations between hours and productivity shocks might be present in the data, with the correlation being positive at low frequencies and negative at higher frequencies. Christiano, Eichenbaum, and Vigfusson refer implicitly to this conjecture when they discuss the fact that the technology shocks they identify have a significantly greater effect on the longer horizons in the variability of hours and other economic variables. It would be interesting to explore more systematically the relevance of the conjecture using filters that can select specific frequencies of the data, such as the band-pass filters advocated by Baxter and King.

2 The Encompassing Test: Some Further Suggestions

The effect of technology shocks on hours thus seems to depend on whether hours are treated as difference- or level-stationary. After arguing that formal, statistical tests of stationarity yield no decisive conclusion when applied to hours, the authors argue that one can still develop a sense of which result is the most robust by following an encompassing strategy.

2. Note that Christiano, Eichenbaum, and Vigfusson (2003) select a quadratic trend, whereas Galí used a linear trend. Furthermore, throughout their papers, Christiano, Eichenbaum, and Vigfusson use the log of (per-capita) hours, while Galí uses the log of total hours.

To do so, they take the VAR they estimated with hours in levels (the one that yielded the positive response of hours to technology shocks) and generate simulated data from it. Next, they apply Galf's procedure to that simulated data set using the difference-stationary assumption and find that it fails to detect the positive correlation. This raises questions about the ability of the difference-stationary specification to identify a positive correlation between hours and technology shocks. Next, they use the second estimated VAR as the generator of simulated data (the one that implies a negative correlation) and re-apply the procedure using the level specification. The procedure does not detect the negative correlation when using Canadian data and reports essentially a zero response of hours when using the American data; note, however, that all confidence bands are wide.³ The upshot of these experiments is that the level specification appears more adept at identifying the truth than the difference-stationary one is. Otherwise said, first-differencing the data may produce such strong distortions that the information in the original data is lost.

I would like to suggest that alternative artificial data sets might be used to run experiments similar to those performed by the authors. For example, a data set created by simulating a standard real-business-cycle model (one for which we *know* that hours and technology shocks would be positively correlated) could be used. Would the difference-stationary specification be able to identify that truth? Furthermore, a model with sticky prices, in which the immediate aftermath of a technology shock is characterized by a decrease in hours, could also be employed. Would the level specification be able to recognize that alternative truth?

3 Industry-Level Data: Support for the Conclusion

Applying Galf's procedure to industry-specific data, Chang and Hong (2003) report results that can be interpreted as favouring the conclusions of Christiano, Eichenbaum, and Vigfusson on the likely effect of technology shocks on hours worked. Among the many subcategories of manufacturing

3. It may be helpful to rewrite the encompassing test using standard notation; let two non-nested hypotheses, H_0 and H_1 , be defined as follows:

H_0 : Hours are I(0) and increase following technology shocks;

H_1 : Hours are I(1) and decrease following technology shocks.

The testing strategy followed by the authors thus takes H_0 as given (simulates data from the first estimated VAR) and verifies whether applying H_1 (first-differencing the simulated data) leads to the conclusion that hours increase following a technology shock. The test is repeated after interchanging the two hypotheses. Written in that way, the procedure resembles some tests for non-nested hypotheses, such as the Cox test.

industries they analyze,⁴ favourable technology shocks lead to increases in hours in more than three out of four cases. These results, however, are arrived at by identifying technology shocks with the permanent innovations to total factor productivity (TFP) measures, instead of the permanent innovations to labour productivity, as Galí's paper proposes.⁵

Conclusions

I very much appreciated reading this paper. I learned a great deal about the effect of technology shocks (and business cycles, more generally) on economic variables. The authors' conclusion—that, on balance, the data support the view that hours worked increases following favourable technology shocks—receives support from a variety of sources. Their paper is therefore certain to rekindle the debate that originated with Galí's result. I believe that an interesting way to enrich this debate would include a thorough examination of specific frequencies at which the authors' and Galí's results might, in turn, be supported by the data.

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4. They examine over 300 subcategories of the manufacturing industry.

5. When Chang and Hong follow Galí exactly and identify technology shocks as the permanent component in labour productivity, hours fall following technology shocks in most industries. Chang and Hong suggest, however, that using labour productivity as the basis for the identification of the technology shocks introduces effects linked to relative price movements rather than TFP changes.

Discussion

Martin Gervais

Summary

The issue tackled in this paper is an important one: the role of technology shocks for business cycle phenomena. It is especially significant in light of recent findings, which can be summarized as follows. Not only are technology shocks unimportant at business cycle frequencies, but real-business-cycle models poorly explain whatever small role they play. A recent paper by Jordi Gali (1999) best exemplifies the second part of this statement. One provocative result suggests that in response to a positive technology shock, hours worked declines for a long period of time, which seems to be at odds with standard real-business-cycle models. Furthermore, Basu, Fernald, and Kimball (1999) and Shea (1998) obtain similar results using very different methodologies; and Francis and Ramey (2002) show that Gali's result is robust to some alternative identifying assumptions.

In this paper, Christiano, Eichenbaum, and Vigfusson challenge Gali's result using the same methodology, which consists of identifying technology shocks in a vector autoregression (VAR) model as the only disturbances that have a long-term impact on productivity. They show that the response of hours worked to a technology shock is sensitive to the measure of hours used in the VAR. In particular, under the level specification (meaning that hours worked appear in the VAR in levels), hours worked responds positively to a positive technology shock, thereby reversing Gali's result, which obtains under the differenced specification (meaning that the first difference of hours worked appears in the VAR). The authors argue that the evidence broadly favours the level specification, which is consistent with the prediction of standard real-business-cycle models.

Whether hours worked is stationary or not is difficult to ascertain given how poorly standard econometrics tests differentiate between persistent and unit-root series. As a first step, the authors use hours worked per capita as opposed to total hours worked, which was used by Galí. It is a step in the right direction, since this is the measure of hours that is built into our standard models. Nevertheless, this series is not clearly stationary, although one would expect hours worked per capita to be stationary in the long term (i.e., in a large sample), given that this series is bounded above and below. Interestingly, the decomposition of this series into hours worked per worker and employment (fraction of the working age population that is working) does not help either, since neither of these series appears to be stationary, whereas hours worked per worker has been declining over the post-war period, and employment has an upward trend. Nevertheless, I will argue below that the distinction between the intensive and the extensive labour margins may be important for other reasons, which is an issue that relates to a common finding in this recent literature.

This finding, consistent with Galí's work, is that technology shocks are unimportant for business cycles. In a similar paper (Christiano, Eichenbaum, and Vigfusson 2003), the authors state that technology shocks in this kind of model account for less than 10 per cent of the cyclical variance of output. Most of my discussion will focus on this result.

1 How Important Are Technology Shocks?

A standard answer to this question can be found in Prescott's (1986a) "Response to a Skeptic," where he suggested that "technology shocks account for more than half the fluctuations [in real output] in the postwar period, with a best point estimate near 75 per cent." The groundwork for these numbers was, of course, his highly cited 1986b paper entitled "Theory Ahead of Business Cycle Measurement."

More recently, Aiyagari (1994, 23) concludes that "Either the contribution of technology shocks must be large (at least 78 per cent), or the predictions concerning the productivity/labor input correlation [which is essentially zero in the data] and the variability of labor input relative to output [about 0.84 in the data] will be incorrect."

The question that arises is: what accounts for the wide discrepancy between these answers and those of the authors? The difference, of course, emanates from the very definition of what constitutes a technology shock.

Recall that Aiyagari was agnostic regarding technology shocks. He derived a model-independent way to measure the importance of technology shocks based on three basic assumptions: (i) the economy operates under perfect

competition; (ii) the absence of external economies of scale; and (iii) the absence of measurement error, systematic or not. Under these three assumptions, and given a labour share that is approximately constant at 66 per cent, Aiyagari shows that unless technology shocks are significant, models will be inconsistent with the data in important ways.¹

The technology shocks that Prescott and Aiyagari referred to were broadly defined as shocks that directly affect the aggregate production technology frontier, a definition that differs widely from the interpretation given to technology shocks in the papers of Galí or Christiano, Eichenbaum, and Vigfusson.

Consider the following reduced-form model, which corresponds to Galí's model and to the differenced specification in the authors' paper:

$$\begin{bmatrix} \Delta f_t \\ \Delta n_t \end{bmatrix} = \begin{bmatrix} C^{11}(L) & C^{12}(L) \\ C^{21}(L) & C^{22}(L) \end{bmatrix} \begin{bmatrix} \epsilon_t^z \\ \epsilon_t^o \end{bmatrix},$$

where f_t represents average labour productivity and n_t is a measure of hours worked. In this simple model, the vector, $[\Delta f_t, \Delta n_t]'$, is expressed as a distributed lag of two types of shocks, labelled ϵ_t^z and ϵ_t^o .

One of the main insights on which Galí builds is that only *permanent* technology shocks should have a permanent effect on productivity. This implies that the unit-root lag associated with shocks that are not permanent technology shocks, ϵ_t^o , should be set equal to zero, that is, $C^{12}(1) = 0$. Before discussing the implications of this assumption, it should be mentioned that for identification purposes alone, there is nothing special about zero; any value of $C^{12}(1)$ would do just as well. In particular, as Sarte (1997) pointed out, permanent changes in income tax rates in real-business-cycle models have a permanent impact on measured productivity. Using this insight as an identifying restriction in the above VAR (i.e., employing the differenced specification), Sarte shows that the implied response to a positive technology shock has the qualitative features of the level specification of Christiano, Eichenbaum, and Vigfusson (see Sarte's Figure 3). This is another example of the well-known fact that any result obtained through a VAR exercise is, to a large extent, dependent on the assumption(s) necessary to identify the parameters of the model.

1. Aiyagari recognizes that moving away from perfect competition or the presence of economies of scale would lower the contribution of technology shocks.

Nevertheless, if one is willing to believe Gali's identification assumption, then one can identify ϵ_t^z as permanent technology shocks. Sure enough, as emphasized by Christiano, Eichenbaum, and Vigfusson, the long-run response to such shocks is in line with the neo-classical growth model, which was designed to explain such phenomena. The short-run response to such shocks should not be viewed as a reason to dismiss or to reinforce how we think of standard real-business-cycle models, nor would the effect of such shocks on the economy be particularly helpful in explaining how the economy behaves at business cycle frequencies. These are permanent shocks, which have the impact that we would expect in the long run. Although it would be highly desirable, as I will argue, to have models capable of replicating the empirical response (whichever one it is) to these shocks at business cycle frequencies, these shocks should not be expected to be the driving force behind business cycle phenomena. The economy does, however, respond to non-permanent technology shocks—identified as ϵ_t^{ϵ} in the model—in ways that are broadly consistent with standard real-business-cycle models.

But what are these other shocks? Arguably, some of them could correspond to monetary or fiscal policy shocks. Nevertheless, an interesting interpretation, which these reduced-form models cannot preclude, is that a significant portion of these shocks corresponds to persistent, but ultimately temporary, technology shocks. With this interpretation, the implicit results of this paper no longer contradict Aiyagari's results, which were based on a much broader view of what represents technology shocks. Ultimately, these shocks may or may not have anything to do with technology per se, but they do have the property that they shift the production technology frontier. In fact, one could argue that the problem is in the language used, not in the theory itself. And if we want to be more precise about what constitutes technology shocks, then we should be able to identify them with particular events. Otherwise, a more agnostic view of these "technology shocks" is perhaps more appropriate.

Evidently, even this interpretation leaves important questions unanswered, since the economy appears to respond differently to permanent technology shocks than it does to persistent (yet temporary) ones.² The next section proposes some avenues that I believe could shed light on this issue.

2. Francis and Ramey (2001) show that a real-business-cycle model with habit persistence and investment adjustment costs is consistent with Gali's results. They do not, however, consider the impact of temporary technology shocks.

2 Interesting Avenues

The above discussion leads me to conclude that we need to think about how the impact of persistent but ultimately temporary technology shocks differs from that of permanent technology shocks. In other words, we must think about models in which the propagation of permanent and transitory shocks to technology differs, and does so in ways that are consistent with the data. This is presumably the conclusion reached by two of the authors of this paper, since they are currently in the process of studying the impact of many different shocks, including temporary and permanent technology shocks, in Altig, Christiano, Eichenbaum, and Linde (2002).

Another potentially important direction is to further explore the implications of modelling both the extensive and the intensive labour margins. As documented by Greenwood, Seshadri, and Vandenbroucke (2002), long-run changes in productivity are important to explain changes in the extensive margin, whereas standard real-business-cycle models with temporary technology shocks mainly concern the intensive margin.³ Andolfatto's (1996) results suggest that a standard real-business-cycle model modified to incorporate labour market search along the lines of Pissarides (2000) is able to explain the fact that about two-thirds of the variation in total hours worked come from the intensive margin and one-third from the extensive margin. Of course, Andolfatto considers only temporary technology shocks. Nevertheless, the transmission of permanent and transitory shocks may be very different in such environments. For instance, one would think that the intensive margin would respond more than the extensive margin following a transitory shock, whereas the opposite might obtain for permanent shocks—at least with a lag.

Finally, vintage capital models, where technology is embodied in capital, may also be of interest. In these models, the reallocation of resources, including employment, following a permanent shock may be very different from that following a temporary shock. For example, one of the features of Campbell's (1998) model is that employment can actually fall following a permanent improvement in technology. Another form of technology shocks that Greenwood, Hercowitz, and Krusell (1998) consider is investment-specific technological change. Their findings suggest that approximately 30 per cent of output fluctuations can be attributed to this form of technological change.

3. There are exceptions, of course, e.g., Hansen (1985) and Rogerson (1988).

Conclusions

This paper makes an important point regarding the empirical response of hours to permanent technology shocks. Although the arguments are not entirely convincing, they certainly go a long way in casting doubts on the results of Galí (1999). More importantly, this type of work makes us think hard about the nature of technology shocks. On all accounts, I believe that more work will be necessary for an agreement to be reached.

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General Discussion*

After thanking the discussants, Martin Eichenbaum noted that assumptions about monetary policy are very important in examining correlations when the Gali model of sticky prices is used for the data-generating process. He also observed that it is easy to put shocks into a structural model, but that it is difficult to identify them in the data. He cited counter-cyclical markups as one possible reason why many of the technology shocks are Granger-caused by monetary policy.

The participants raised a number of issues, particularly related to monetary policy. David Laidler noted that since technology shocks originated from the residuals of a production function, which are linked to the interest rate through the aggregation of capital and output, it was not surprising to find that technology shocks were Granger-caused by monetary policy. Eichenbaum responded that capital utilization and labour variables are more important than the stock of capital, but he allowed for the possibility that more disaggregation may be necessary in exploring this issue. James Nason also mentioned that he was not surprised to see the monetary authority accommodating technology shocks in the real-business-cycle monetary model, given the aggregate demand and supply equations combined with a strong quantity-theory component.

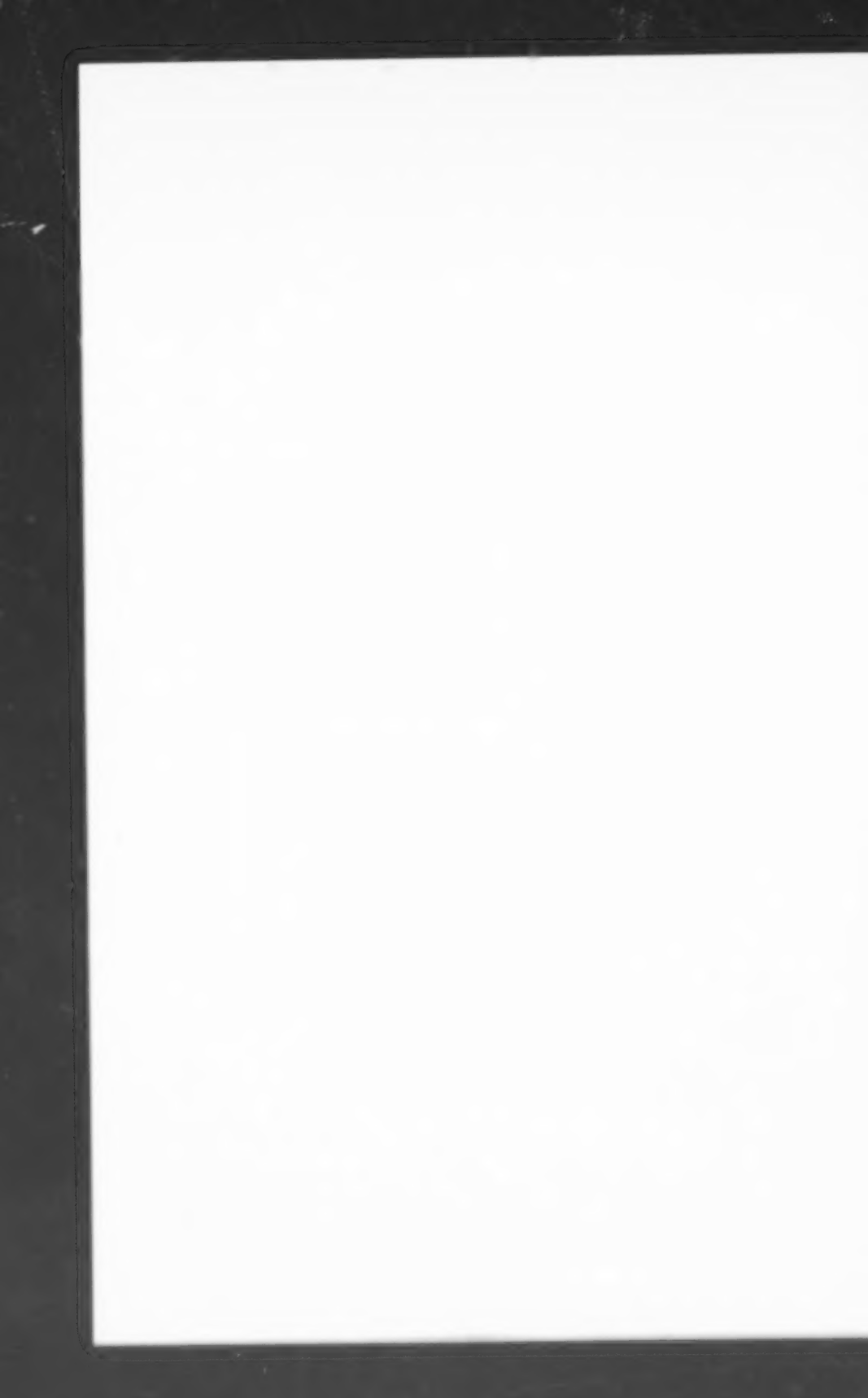
Nason suggested that to be consistent with Gali's point of correlation, the axes in the paper's scatter plots should be the correlation between permanent and transitory components from the SVAR. Citing previous work, he suggested that the best way to deal with the non-cyclical behaviour of labour

* Prepared by Nooman Rebei and David Turk.

market variables would be to examine the real wage over the cycle and to consider issues such as worker heterogeneity.

Given the fact that real-business-cycle models do not explain short- and medium-run dynamics very well, Michael Woodford inquired whether the paper's model improved on this shortcoming. Eichenbaum replied that it did not. He added, however, that the paper was more concerned with the identification of shocks than with explaining short-run dynamics.

Citing his work based on Eichenbaum's model, Frank Smets concluded that not only do technology shocks lead to a negative correlation between output and employment, but they are, in fact, significant. Eichenbaum responded that since the model satisfies the identifying assumptions, the different results constitute evidence against the structural model. Further discussion initiated by Steven Ambler regarding the role of monetary policy in the model led Eichenbaum to conclude that the model must be misspecified if one cannot obtain the correct impulse-response functions. He also felt that future work must reach a conclusion in this matter.



Section 4: **Small Open-Economy Models**

New Keynesian, Open-Economy Models and Their Implications for Monetary Policy*

David Bowman and Brian Doyle

Introduction

Although there were some clear antecedents, including most notably Svensson and van Wijnbergen (1989), the publication of Obstfeld and Rogoff's (1995a) "Exchange Rate Dynamics Redux" marked the beginning of a surge in work on a new class of open-economy macroeconomic models. A few key features distinguish this class of models:

- optimization-based dynamic general-equilibrium modelling;
- sticky prices and/or wages in at least some sectors of the economy;
- incorporation of stochastic shocks;
- evaluation of monetary policies based explicitly on household welfare.

This paper summarizes some of the work in this field, emphasizing its implications for monetary policy. New Keynesian, open-economy models have not yet solved long-standing debates, but they have clarified a number of important issues. Because the work incorporates sticky prices or wages into optimization-based general-equilibrium models, this literature holds the

* We wish to thank our discussant, Frank Smets, participants of the Bank of Canada's November 2002 conference, Paolo Pesenti, Philippe Bacchetta, and especially Dale Henderson for helpful comments and suggestions. We are, of course, responsible for any errors. This paper represents views of the authors and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System or other members of its staff.

promise of combining some of the internally consistent long-run properties of international real-business-cycle models with short-run Keynesian features that allow for a discussion of monetary policy and its effects on aggregate demand. By incorporating stochastic shocks, these models are able to address the effects of risk on prices, wages, trade flows, and capital flows and the ways that monetary policy affects these risks. Perhaps most importantly, evaluation of policy based on household welfare has provided a new perspective on the analysis of the impacts of the transmission of shocks across countries and exchange rate pass-through on optimal monetary policy rules and international policy coordination. However, while there have been new conceptual insights from this literature, there has been considerably less work on empirical estimation or testing of these new models. Furthermore, the literature is not yet at the stage where it can confidently make quantitative suggestions as to how monetary policy should operate in an open economy.

The remainder of the paper is divided into four sections. The first briefly outlines the original Redux model and its implications. The second section discusses a few of the many extensions that have been made to the Redux model in the years since its publication. It focuses on the extensions we believe are qualitatively most important for understanding optimal monetary policy in an open economy. The third examines the implications of this literature for optimal monetary policy for a single country. The fourth section examines the implications for optimal monetary coordination across countries, and conclusions follow.

1 Exchange Rate Dynamics Redux

Obstfeld and Rogoff (1995a) introduce a two-country model with a continuum of differentiated traded goods; a fraction n of the goods is produced domestically, and the remaining fraction, $1-n$, is produced abroad. Domestic and foreign households and governments are modelled as having identical preferences over an index of all the differentiated goods (indexed by z) produced in the world:

$$C = \left[\int_0^1 c(z)^{\frac{\theta-1}{\theta}} dz \right]^{\frac{\theta}{\theta-1}} \quad G = \left[\int_0^1 g(z)^{\frac{\theta-1}{\theta}} dz \right]^{\frac{\theta}{\theta-1}}, \quad (1)$$

where $c(z)$ represents the household's consumption of good z , and $g(z)$ represents the government's consumption. (Throughout, foreign counterparts to domestic variables will be designated by an asterisk, $(*)$; for example, foreign consumption of good z is $c^*(z)$, and the foreign consumption index is C^* .)

Obstfeld and Rogoff assume that the law of one price holds for every good:

$$p(z) = e p^*(z), \quad (2)$$

where $p(z)$ ($p^*(z)$) is the price of good z in domestic (foreign) currency, and e is the exchange rate. The price index associated with preferences of form (1) is:

$$\begin{aligned} P &= \left[\int_0^1 p(z)^{1-\theta} dz \right]^{\frac{1}{1-\theta}} \\ &= \left[\int_0^n p(z)^{1-\theta} dz + \int_n^1 e p^*(z)^{1-\theta} dz \right]^{\frac{1}{1-\theta}}. \end{aligned} \quad (3)$$

Formally, each household is modelled as producing its own individual good with its own labour; however, this is equivalent to assuming that labour is purchased competitively at a market-clearing flexible wage. While the labour market is competitive and the wage is flexible, each firm is a monopolistic competitor and prices are set one period in advance in the producer's currency. Equation (1) implies a constant elasticity of demand for each good and, as a result, each firm would set its price at a constant markup over marginal cost if prices were flexible. Assuming that κ units of labour are required to produce one unit of a good, the firm's desired price is:

$$p(z) = \left(\frac{\theta}{\theta - 1} \right) \kappa w. \quad (4)$$

Redux analyzes a perfect foresight setting and then introduces a one-time unforeseen policy shock. In the model, there is an integrated world capital market where agents may buy or sell risk-free indexed debt, yielding a real interest rate, r , in terms of the common basket of goods. Because this is a perfect foresight model and because the law of one price holds for all goods, real interest rate equalization across countries implies that uncovered interest rate parity holds both *ex ante* and *ex post*,

$$1 + i_t = \frac{e_{t+1}}{e_t} (1 + i_t^*), \quad (5)$$

where i_t is the nominal interest rate. Households act to maximize a utility function of the form

$$U_t = \sum_{s=t}^{\infty} \beta^{s-t} \left[\frac{1}{1-\rho} C_s^{1-\rho} + \frac{\chi}{1-\epsilon} \left(\frac{M_s}{P_s} \right)^{1-\epsilon} - \frac{\kappa}{v} y_s(z)^v \right], \quad (6)$$

where M represents holdings of money and $y(z)$ can be interpreted either directly as output or indirectly as the amount of labour the household supplies. The first-order conditions for utility maximization imply that the household will choose consumption and money holdings so that

$$C_{t+1} = [\beta(1+r_t)]^{\frac{1}{\rho}} C_t, \quad (7)$$

$$\frac{M_t}{P_t} = \left[\chi C_t^{\rho} \left(\frac{1+i_t}{i_t} \right) \right]^{\frac{1}{\epsilon}}. \quad (8)$$

A positive monetary shock to the home country will have some of the same effects found in the standard Mundell-Fleming model: the shock will lead domestic households to increase their aggregate consumption demand and will lead to a depreciation of the exchange rate and an increase in net domestic claims on foreigners. Perhaps surprisingly, though, all of these effects are largely permanent. Equation (7) implies that, all else given, households will raise not only current consumption but also all future consumption by using some of the current income increase to increase asset holdings. Although the real interest rate may move to offset some of this effect, changes to relative consumption demand (C/C^*) will be permanent because domestic and foreign households face the same real interest rate. For the same reasons, the model implies that there is no exchange rate overshooting in response to a permanent monetary shock—as just argued, relative consumption will immediately jump to its new level for any shock and by definition a permanent money shock will cause the relative money supply to immediately jump to its new level, hence the exchange rate and relative money demand will also immediately jump to the new equilibrium levels.

As these examples show, explicit modelling of general-equilibrium dynamics leads to some conclusions about the effects of policy that differ from the conclusions in older Keynesian models, while still allowing for many Keynesian effects. There are also some surprising conclusions from the explicit modelling of welfare-maximizing agents: although it might appear that a permanent domestic money shock leaves domestic agents better off and foreign agents worse off, Obstfeld and Rogoff show in the Redux model that domestic and foreign agents experience the same welfare gain. The gain from increasing output follows from the monopoly power of

firms. Because of this market power, output is suboptimally low; the welfare gain to agents from a monetary increase comes from the expansion of output it causes, which pushes output closer to its optimal level. Because domestic and foreign agents are affected to the same degree by this market imperfection, both gain equally by its reduction.

2 Extensions

Lane (2001) and Sarno (2001) survey many of the extensions to the original Redux model.¹ Here we focus on the extensions that we believe have the most important qualitative implications for the conduct of monetary policy in an open economy. We divide these extensions into those having to do with intratemporal (static) decisions and those associated with intertemporal (dynamic) decisions.

2.1 Static extensions

2.1.1 *Preferences between domestic and foreign goods*

Warnock (1998) introduces home bias into the Redux framework by assuming that domestically produced goods receive greater weight in the consumption indexes of domestic agents. Home bias results in a domestic monetary shock having a greater effect on domestic welfare than foreign welfare, because domestic agents benefit more from the expansion of domestic output. The exchange rate will also overshoot in response to a permanent monetary shock, because home bias allows the real exchange rate to be affected by shifts in wealth across countries and hence for differences in the real interest rate as measured in domestic and foreign baskets of consumption goods. An appendix to the Redux model introduces non-traded goods, as do Hau (2000) and Obstfeld and Rogoff (2000, 2002). This is an alternative to the form of home bias studied by Warnock that similarly allows for deviations from purchasing-power parity because tastes are no longer identical and because the law of one price will not hold for non-traded goods.

Several papers relax the Redux assumption that the elasticity of substitution between domestic and foreign goods is identical to the elasticity of substitution between different domestic goods. These papers include Corsetti and Pesenti (2001a); Chari, Kehoe, and McGrattan (1998); and Tille (2001). These papers model the consumption index as:

1. For more papers in the "new open-economy macroeconomics" literature, see Brian Doyle's Web site on the topic at http://www.geocities.com/brian_m_doyle/open.html.

$$C = \left[\gamma C_h^{\frac{\phi-1}{\phi}} + (1-\gamma) C_f^{\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}}, \quad (9)$$

where

$$C_h = \left[\int_0^n c(z)^{\frac{\theta-1}{\theta}} dz \right]^{\frac{\theta}{\theta-1}} \quad C_f = \left[\int_n^1 c(z)^{\frac{\theta-1}{\theta}} dz \right]^{\frac{\theta}{\theta-1}}, \quad (10)$$

so that the elasticity of substitution between domestic and foreign goods is ϕ , while the elasticity of substitution between domestic goods is θ . Tille (2001) shows that an unexpected monetary expansion still improves home welfare relative to foreign welfare if the elasticity of substitution between home and foreign goods is larger than the elasticity of substitution of goods within the home and foreign economies. Home welfare relative to foreign welfare is reduced when the opposite is true. Only in the case where they are equal do home and foreign benefit equally. If the gap between the two elasticities is large enough, then a home monetary expansion will have a "beggar-thy-neighbour" effect on foreign welfare, reducing its absolute welfare. Likewise, monetary policy may even have a "beggar-thyself" effect if the gap the other way is large enough.

Corsetti and Pesenti (2001a) analyze what has become a particularly important case. Setting $\phi = 1$ yields a Cobb-Douglas form for the consumption index:

$$C = C_h^\gamma C_f^{1-\gamma}. \quad (11)$$

A unit elasticity of substitution implies that total household expenditures on domestic and foreign goods are constant. Because a rise in the foreign price of domestic goods will result in a proportionate decrease in the quantity of foreign demand for domestic goods, export revenue remains constant. The importance is that if the current account begins in balance, it will remain so.² As a result, the permanent effects on the current account that Obstfeld and Rogoff emphasize in the Redux model will not occur. This property allows Corsetti and Pesenti to solve the model in closed form, without the need for linear approximation. Another implication of this assumption is that in equilibrium, foreign and domestic consumption of traded goods will be perfectly correlated because the unitary elasticity of demand protects

2. This same feature was emphasized by Cole and Obstfeld (1991) and Newberry and Stiglitz (1984).

revenue from shocks. If utility is separable between traded consumption and the other variables that affect welfare, then the fact that traded consumption is perfectly correlated means that agents do not require securities markets to share risk; risk-sharing automatically occurs in this case. If utility is non-separable in traded consumption, then risk-sharing will not usually imply perfect correlation between cross-country tradables consumption, because the marginal utility of tradables consumption will fluctuate with movements in the other variables affecting welfare. This condition implies that the ratio of domestic to foreign tradables consumption should fluctuate as well, unless shocks are global and have common effects across sectors.

2.1.2 *Pass-through from exchange rates to domestic prices*

The Redux model assumes that the law of one price holds for all goods. Aggregating across goods implies purchasing-power parity,

$$P = eP^* \quad (12)$$

As is well known, most exchange rates exhibit substantial and long-lasting deviations from purchasing-power parity. Although the introduction of non-traded goods would allow for deviations from purchasing-power parity, as documented by Engel (1999) and Rogers and Jenkins (1995), deviations from the law of one price for traded goods appear to explain the majority of fluctuations in real exchange rates. This evidence has led a number of authors to explore alternative pricing structures. The Redux model assumed that firms set prices in the sellers' currency, what has come to be called producer currency pricing (PCP). Betts and Devereux (1996, 2000a, 2000b) introduce the alternative assumption that a fraction of firms set prices in the buyers' currency or local currency pricing (LCP). Devereux and Engel (1998, 2000); Kollmann (2001); Chari, Kehoe, and McGrattan (1998); and Bergin and Feenstra (2001) have all incorporated the LCP assumption in their work. Letting s represent the fraction of foreign firms who set prices in domestic currency and using $\bar{p}$ to indicate that a price is fixed, Betts and Devereux's formulation alters equation (3) to have the form

$$P = \left[\int_0^n \bar{p}(z)^{1-\theta} dz + \int_n^{n+(1-s)s} \bar{p}^*(z)^{1-\theta} dz + \int_{n+(1-s)s}^1 e \bar{p}^*(z)^{1-\theta} dz \right]^{\frac{1}{1-\theta}} \quad (13)$$

Corsetti and Pesenti (2001b) alternatively model deviations from the law of one price by assuming that foreign firms are able to respond to a fraction of exchange rate movements, which in this framework alters the form of the domestic price index to:

$$P = \left[\int_{-1}^n \bar{p}(z)^{1-\theta} dz + \int_n^1 (e^{1-s} \bar{p}^s(z))^{1-\theta} dz \right]^{\frac{1}{1-\theta}}. \quad (14)$$

To understand the differences in implication, it is useful to compare full PCP ($s = 0$) with full LCP ($s = 1$). In the Redux model, there is full pass-through of exchange rate movements to import prices. With full PCP, movements in the exchange rate will affect the consumer price index. Taking a log approximation (where a hat (^) over a variable indicates log deviation from steady state) to equation (3) yields

$$\hat{P} = (1-n)\hat{e}, \quad (15)$$

implying that a 1 per cent movement in the exchange rate will have an effect on consumer prices equal to the share of imports in consumption. A rise in the exchange rate will shift demand towards domestic goods and away from imports by raising the relative price of imports. On the other hand, with full LCP there is no pass-through from the exchange rate to import prices, and equations (13) and (14) imply that the price level is completely unaffected by exchange rate movements in the short run. In this world, exchange rate movements will not shift relative demand for imports and will not act to equilibrate demand in response to economic disturbances.

Local currency pricing is able to capture several key empirical features. The assumption of full LCP implies that short-term movements in the nominal and real exchange rate will be perfectly correlated, which is similar to the evidence presented in Mussa (1986); there is little or no short-term pass-through from exchange rates to consumer prices, which is similar to evidence for the United States; and full or partial LCP will tend to produce greater variability in the nominal exchange rate, because larger movements in the exchange rate are required to affect the relative price of imports and equilibrate changes in import demand. However, as emphasized by Obstfeld (2001), the LCP assumption implies that when a country's exchange rate depreciates, its terms of trade should improve (import prices are unaffected and export prices, which are fixed in terms of the foreign currency, will rise in terms of the domestic currency), which is counter to the empirical evidence (Obstfeld and Rogoff 2000). By failing to differentiate between consumer prices and wholesale or intermediate prices, the LCP literature cited above effectively discounts the economic importance of significant pass-through of exchange rate movements to wholesale import prices. In a survey of the evidence, Goldberg and Knetter (1997) conclude that roughly half of exchange rate movements are passed on to U.S. wholesale import

prices within one year, which is a considerably larger short-term effect than found for consumer price indexes.

In response to this type of evidence, a number of authors have recently begun to model richer environments in which wholesale import prices differ from consumer prices in economically important ways. Burstein, Neves, and Rebelo (2000); Burstein, Eichenbaum, and Rebelo (2002); McCallum and Nelson (1999, 2000); and Corsetti and Dedola (2002) all consider environments in which the marketing and distribution of imported goods require the use of non-traded goods as an input. Obstfeld (2001) and Engel (2002) consider environments in which firms combine domestically produced intermediate goods with imported intermediates, employing PCP to produce a non-traded consumption good. If the price of the consumption good is sticky, then exchange rate changes will have no impact on consumer prices, but will affect the terms of trade and induce firms to switch demand between domestic and imported intermediate goods.

Several recent papers have begun to consider the endogeneity of the currency pricing choice as well. Devereux and Engel (2001) show that under complete risk-sharing, all firms will denominate their sales in the most stable currency regardless of whether it is domestic or foreign. With incomplete risk-sharing, they conclude that LCP may be an equilibrium outcome, but that PCP is not a robust outcome. Bacchetta and van Wincoop (2002) conclude that PCP may be an equilibrium outcome if domestic firms have a high market share in foreign markets and the elasticity of substitution between sectors is low. Corsetti and Pesenti (2002) analyze the possibility of multiple equilibria. If exchange rate variability is low, then LCP is more attractive to firms, and if firms practice LCP, then monetary authorities may have an incentive to keep exchange rate variability low (see section 3). Conversely, if exchange rate variability is high, then firms have an incentive to practice PCP, and in this case monetary authorities are more likely to choose a flexible exchange rate regime.

2.1.3 *Wage stickiness versus price stickiness*

While the Redux paper assumes effectively that nominal wages are perfectly flexible and output prices are sticky, other papers have reversed the two, making wages sticky and prices perfectly flexible.³ Household utility (equation (6)) now depends negatively on work effort, where each household has differentiated labour— L replaces $y(z)$, and k is the marginal disutility of effort. Each household supplies labour to each firm at a wage set

3. Among those doing so in this literature were Obstfeld and Rogoff (1996, chapter 10), Corsetti and Pesenti (2002), and Obstfeld and Rogoff (2000).

one period in advance. The corresponding aggregate nominal wage is an index of the nominal wages of each worker,

$$W = \left[\int_0^1 W(i)^{1-\phi} di \right]^{\frac{1}{1-\phi}}. \quad (16)$$

If each firm has a production function,

$$y(z) = \left[\int_0^1 L(z, i)^{\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}}, \quad (17)$$

which produces a differentiated good, then prices will be a constant markup over wages, as in equation (4). Perfectly competitive output markets, when $\theta \rightarrow \infty$, will mean that prices move one-for-one with nominal wages.

Corsetti and Pesenti (2002) and Obstfeld and Rogoff (2000) argue that sticky wages and flexible prices are closer to reality. Despite this point, if prices are set as a constant markup over marginal cost, then for certain applications it may not matter whether prices or wages are sticky. Erceg, Henderson, and Levin (2000) show one example of when it does matter—in a closed economy with both staggered price- and staggered wage-setting, the monetary authority can no longer replicate the flexible price equilibrium.

2.2 Dynamic extensions

As emphasized in the Redux model, consumption smoothing will tend to lead to permanent effects, even of monetary shocks. These permanent effects imply that the steady state of the model will move in response to shocks, making linearizing around a fixed steady state a dubious proposition. By fixing prices for one period only and examining the perfect foresight solution with a single unexpected shock to policy, Obstfeld and Rogoff were able to properly take into account the change in steady-state values. However, while the assumptions that prices were fixed for only one period and that shocks were unexpected make the model more analytically tractable, they do not lead to very satisfying dynamics.

Other papers have relaxed the assumption of perfect foresight or allowed for richer dynamic structures, but have needed in turn to confront the issue that wealth effects of consumption smoothing can cause changes in the steady state. Most papers have chosen to make assumptions that effectively shut down this channel by assuming that financial markets are complete or that preferences are such that the equilibrium mimics complete financial

markets, as discussed in section 2.1.1. A few papers have recently made alternative assumptions that allow for transitory shifts in net foreign assets while still guaranteeing a unique long-run steady state. This later approach is promising; however, it is important to note that it may not be economically significant in terms of the accuracy of existing model solution procedures whether relative consumption levels have an exact unit root (which implies there is no unique steady state) or a near unit root (which implies that there is a unique steady state but that equilibrium values may wander very far from it). Merely guaranteeing a unique steady state may not guarantee that current solution procedures are accurate.

2.2.1 Stochastic shocks

Several authors have analyzed monetary shocks within a stochastic framework (for example, Obstfeld and Rogoff (1998, 2000), Bacchetta and van Wincoop (2000), and Devereux and Engel (1998)). In these papers, monetary shocks only have real effects for one period, since wages are pre-set for one period, and the models use the Corsetti and Pesenti assumptions of a zero initial current account and a unitary elasticity of substitution between home and foreign tradables. Households now maximize expected utility in the face of monetary shocks⁴ and disutility of effort shocks. All shocks to the model are assumed to be lognormally distributed.⁵ Obstfeld and Rogoff (1998) need only linearize the money market equilibrium around the non-stochastic steady state with a constant growth rate in consumption and the money supply. Others assume that household utility is logarithmic in real money balances in order to obtain closed-form solutions.

In this framework, the volatility of variables can affect welfare and first moments of endogenous variables, including the exchange rate, terms of trade, consumption, and price-setting. If workers set their wages one period in advance, they will set their wages such that the expected marginal utility of the consumption an extra hour of labour can buy equals the expected marginal disutility of providing the extra hour of labour.

$$W = \left(\frac{\phi}{\phi - 1} \right) \frac{E(\kappa L)^{\gamma}}{E(LP^{-1}C^{-\rho})} \quad (18)$$

4. In these papers, the money supplies at home and abroad follow a random walk, $m_t = m_{t-1} + \mu_t$, where μ_t is normally distributed with mean zero and variance σ_{μ}^2 .

5. Remember that if x is normally distributed with mean μ and standard deviation σ , then

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

Making use of the assumption that all endogenous variables are lognormal (since all shocks are), the nominal wage can be rewritten in terms of the means, variances, and covariances:

$$W = \left(\frac{\Phi}{\Phi - 1} \right) \frac{E(C)E(L)^{\frac{1}{\Phi-1}}}{E(P)^{\frac{1}{\Phi-1}}E(C)^{\frac{1}{\Phi-1}}} \exp \left[\frac{(\sigma_C^2 + \sigma_L^2)}{2(\Phi-1)} + \frac{(\sigma_P^2 + \sigma_C^2)}{2(\Phi-1)} + \frac{(\sigma_L^2 + \sigma_P^2)}{2(\Phi-1)} \right] \quad (19)$$

Since households set their wages one period in advance, not only do the expected values of variables influence their decisions, but variances do as well. For example, since workers like consumption and dislike work effort, high levels of consumption at the same time they are required to work more, a positive σ_{CL} will imply that they will raise their wages to reduce their expected workload. A higher disutility of effort at the same time when workers must provide more labour, a positive σ_{LP} , also means that workers will raise their pre-set wages.

In a stochastic framework with nominal rigidities, the variance as well as the level of monetary policy shocks can therefore also have an effect on the level of variables in the economy, and more importantly its *ex ante* welfare. While some might question the relevance of looking at monetary policy shocks to implement monetary policy, it will be important when we look at monetary policy rules. Under floating exchange rates and in the absence of other shocks, the more variable monetary policy, the more variable the nominal exchange rate and the higher the variability of consumption, which results in a reduction of welfare. Higher monetary volatility further reduces welfare by increasing pre-set wages, moving the economy farther away from the competitive level, thereby reducing the level of consumption. Devereux and Engel (1998) show that this reduction in the level of consumption—resulting from an increase in monetary policy's variance—also holds true under LCP, even though there is no longer any effect on the variance of consumption. Monetary volatility will also have an effect on the level of exchange rate, but, surprisingly, higher monetary volatility will reduce, not raise, the risk premium. Obstfeld and Rogoff (1998) point out that this result may help explain part of the "forward premium puzzle." Bacchetta and van Wincoop (1998, 2000) show in a model with LCP and non-separable preferences between consumption and leisure, that nominal exchange rate volatility does not necessarily have a negative effect on trade flows and likely has a negative effect on capital flows. Furthermore, the welfare effects of exchange volatility diminish the larger a country is as a percentage of the world economy—since most goods are produced at home and their prices are set. Obstfeld and Rogoff (1998) show through a simple illustration that the size of the welfare effect of a reduction in exchange rate volatility, holding all else constant (including the variance of monetary policy shocks), may be quite large—1 per cent of GDP per year, in their case.

Despite theoretical work that shows a link between exchange rate uncertainty and both prices and real macroeconomic variables, earlier empirical work is mixed. Papers that look for direct links between volatility and economic variables do not find much of a relationship. A sizable literature that estimates the trade-suppressing effect of nominal exchange rate volatility has found small and usually insignificant results,⁶ consistent with Bacchetta and van Wincoop (2000). Baxter and Stockman (1989) and Flood and Rose (1995) found little or no relationship between exchange rate volatility and a wide number of other real macroeconomic variables. Work that has focused instead on differences in regimes has been more successful in finding sizable changes in variables, but at the cost of being less able to point directly at the cause. McCallum (1995) and others show that trade within borders, where nominal exchange rate volatility is zero and real exchange rate variability low, is significantly higher than trade across borders. Rose (2002) summarizes a now large body of work that shows much higher trade flows between countries within a currency union than countries not part of such a union. Output in nations belonging to currency unions is higher as well. A recent paper by Broda (2002) finds that, over the period 1980 to 1996, national price levels⁷ are about 20 per cent higher in countries that he classifies as having fixed exchange rates as compared with those with floating exchange rates. As in the earlier papers, however, he finds a weak relationship between national price levels and the choice of a fixed or flexible exchange rate in developed countries. Further work in light of these recent studies may yield additional positive evidence.

2.2.2 *Asset markets*

The original Redux model assumed that the only financial assets available to households were money and a risk-free indexed bond. Because of the resulting market incompleteness, the model implied that even monetary shocks could shift wealth across countries via movements in the current account, leading to permanent effects on the equilibrium of the model and on welfare. In subsequent work, several authors have assumed instead that financial markets are complete, including Chari, Kehoe, and McGrattan (1998); Devereux and Engel (2000); and Engel (2002). This assumption shuts down one potential source of distortion to the economy, leaving only the distortions from sticky prices and the market power of the firm in the original Redux model. It also shuts down any effects on the current account in that model. Intuitively, this occurs because agents will trade assets in such a way as to avoid shifts in wealth due to monetary shocks. Alternatively,

6. Surveyed by Côté (1994) and McKenzie (1999).

7. Defined as the ratio of a currency's purchasing-power-parity value to its market value.

with complete asset markets, agents have no need to borrow or lend in international spot markets for capital, because they can hold an asset portfolio that allows them to receive their desired stream of income in any given state of nature. The assumption of complete markets has a practical advantage of making the model easier to solve, since current account movements impart dynamics to the original Redux model that made a closed-form solution impossible. Although market completeness clearly affects the qualitative implications of these models—with market incompleteness implying that monetary shocks may permanently affect relative consumption levels across countries—Chari, Kehoe, and McGrattan (1998) and Betts and Devereux (2001) conclude that when they considered monetary shocks, the quantitative effect of complete versus incomplete markets is small in their calibrations. (Betts and Devereux conclude that financial market completeness does matter when considering fiscal policy shocks.) Of course, as discussed above, if there is a unitary elasticity of demand between domestic and foreign traded goods, it is irrelevant whether markets are complete, since the equilibrium will coincide with the complete markets outcome regardless of what or how many assets are actually traded.

2.2.3 *Current account dynamics*

The intertemporal approach to the current account gained popularity within academic circles in the early 1980s.⁸ The approach was an extension of the permanent income hypothesis to an open-economy setting. It viewed the current account as a means through which domestic residents attempt to smooth their consumption by borrowing from or lending to the rest of the world. In our current framework, using a stochastic version of equation (7) and assuming a constant interest rate,

$$r = 1 - \frac{1}{\beta}$$

implies a constant path for expected consumption:

$$C_t = E_t(C_{t+1}). \quad (20)$$

The focus on the intertemporal choice to borrow or lend from abroad reduced emphasis on intratemporal competitiveness, as measured by the real exchange rate, and instead emphasized households' expectations of future income. Indeed, the existing empirical literature on the intertemporal approach has assumed that there is a single aggregate good for which the

8. See Buiter (1981), Obstfeld (1982), Sachs (1981), and Svensson and Razin (1983). Obstfeld and Rogoff (1995b) provide a comprehensive survey.

law of one price holds, so that the real exchange rate does not even enter the equations.⁹ The original Redux model held out the promise of reincorporating some of these effects into intertemporal models of current account behaviour. However, as noted above, much of the subsequent work has made assumptions on either asset structure or preferences that have the effect of shutting down current account dynamics.

Are current account dynamics important for understanding monetary policy or the economy more generally? Central banks and international institutions such as the IMF often worry about current account balances when they fall substantially into deficit. The assumption of complete markets allows for linearizing models around a zero current account balance. However, if markets are incomplete, any variety of monetary or non-monetary shocks may eventually drive current account balances away from zero, and as emphasized by Benigno (2001a), solutions around non-zero current account balances can have materially different implications for the effects of monetary policy. Lane and Milesi-Ferretti (2002a,b) empirically link net foreign asset positions to long-run values of the real exchange rate, suggesting that optimal monetary policy responses may depend on movements in the current account.

Beginning with Hall (1978), rational expectations versions of the permanent income hypothesis have been tested frequently, using both aggregate and individual data. While they are capable of explaining broad movements in consumption and saving, tests of the hypothesis are usually statistically rejected. In light of this, it is not surprising that rational expectations versions of the intertemporal approach are typically statistically rejected as well. Nonetheless, we argue that the hypothesis captures some important features of current account dynamics that deserve inclusion in New Keynesian open-economy models.

Defining CA_t as the current account, A_t as net claims on foreign assets, Y_t as GDP, and I_t as investment, the savings-investment identity,

$$CA_t = r_t A_t + Y_t - C_t - I_t - G_t, \quad (21)$$

provides the relevant notion of income,

9. Of course, there were also richer general-equilibrium models of the intertemporal approach that included, for example, non-tradables or differing sets of tradables produced by different countries, thereby allowing the real exchange rate (measured as the relative price of non-tradables) or the terms of trade to affect the current account (Obstfeld 1982; Dornbusch 1983; Obstfeld and Rogoff 1996, chapter 4), but these did not receive as much empirical attention.

$$Q_t = Y_t - I_t - G_t. \quad (22)$$

This variable, which is termed "net income," represents the non-interest income available for private consumption after providing for investment and government demand of goods and services. Its role in the intertemporal approach is similar to the role of labour income in the life-cycle/permanent income hypotheses.

Combining equations (20)–(22) with the household's intertemporal budget constraint yields the implication that the current account should respond only to temporary deviations of net income:

$$CA_t = Q_t - Q_t^p, \quad (23)$$

where Q_t^p is the expected permanent level of net income. According to the equation, temporary shocks to output, investment, or government spending should affect the current account and permanent shocks should not, because consumers will attempt to smooth consumption in the face of temporary shocks by borrowing from or lending to the rest of the world, while permanent shocks cannot be smoothed away. Ahmed (1987) found some support for this hypothesis using historical data for the United Kingdom.

Following Campbell (1987), equation (20) can be rewritten in a form that implies that the current account should equal the expected present discounted value of all future declines in net income:

$$CA_t = E_t \left(\sum_{j=1}^{\infty} \frac{1}{(1+r)^j} \Delta Q_{t+j} \right). \quad (24)$$

Campbell's form of the equation emphasizes that the current account reflects expected future changes in the domestic output available to households. Thus, the current account should be in deficit if net income is expected to grow, while it should be in surplus if net income is expected to decline. Sheffrin and Woo (1990), Otto (1992), and Ghosh (1995) have tested this prediction for various countries. While the restrictions are formally rejected for most countries, the model's predictions often appear to work well in economic terms.

The equations above are only valid for a small open economy subject to idiosyncratic shocks. Simple extensions of the intertemporal approach to a global general equilibrium with larger countries or global shocks replace net income in these equations with relative net income:

$$RQ_t = Q_t - Q_t^w, \quad (25)$$

where Q_t^w is average world net income.¹⁰ If all countries wish to borrow, then interest rates will rise but there will be little effect on capital flows because there is no counterparty willing to lend. Thus, if a shock is global, then general-equilibrium versions of the intertemporal approach predict that there should be little or no effect on the current account, while if a shock is country-specific, it should affect the current account. Glick and Rogoff (1995) have tested this implication of the theory. They find that the current account does in fact appear to respond more to country-specific productivity shocks than to global shocks.¹¹

To what extent is this useful? Campbell's formula implies that the current account should be in deficit when households expect future relative net income to grow, and that it should be in surplus when relative net income is expected to decline. As seen in Table 1, on a rough level this matches the experiences of the United States, Germany, and Japan during the 1990s. The United States had a current account deficit of \$111 billion measured in 1996 prices at the start of the decade, and its relative net income grew at a much faster rate than the historical average, while Germany and Japan both began with current account surpluses and experienced below average growth in relative net income during the decade.

To more formally test the ability of the intertemporal approach to fit the experience of the 1990s, we formed an estimate of the expected present value of future changes in relative net income for each quarter over the period 1960:1–2000:1 and compared this to the actual current account. We first estimated a two-equation system for each country, regressing relative net income and the current account on their lagged values using quarterly data up to 1989:4. At each time period, we then used these estimated equations to form a forecast of all future changes in relative net income based on the data available at that date. Using this forecast, we then calculated the implied expected present value of declines in relative net income. According to the theory, if our estimated equations are an accurate representation of household's expectations, this expected present value should equal the current account. The results are shown in Figure 1. In each case, the intertemporal approach is statistically rejected at the 1 per cent level. However, on an informal level, the theory does surprisingly well for the United States and Japan, though less well for Germany. In particular, the

10. In our empirical exercises, average "world" income is calculated using a GDP-weighted average of net income for the G-7 countries.

11. Glick and Rogoff find little response to either country-specific or global government spending shocks. They attribute this result to the difficulty of identifying temporary spending shocks.

Figure 1
Actual and implied current account

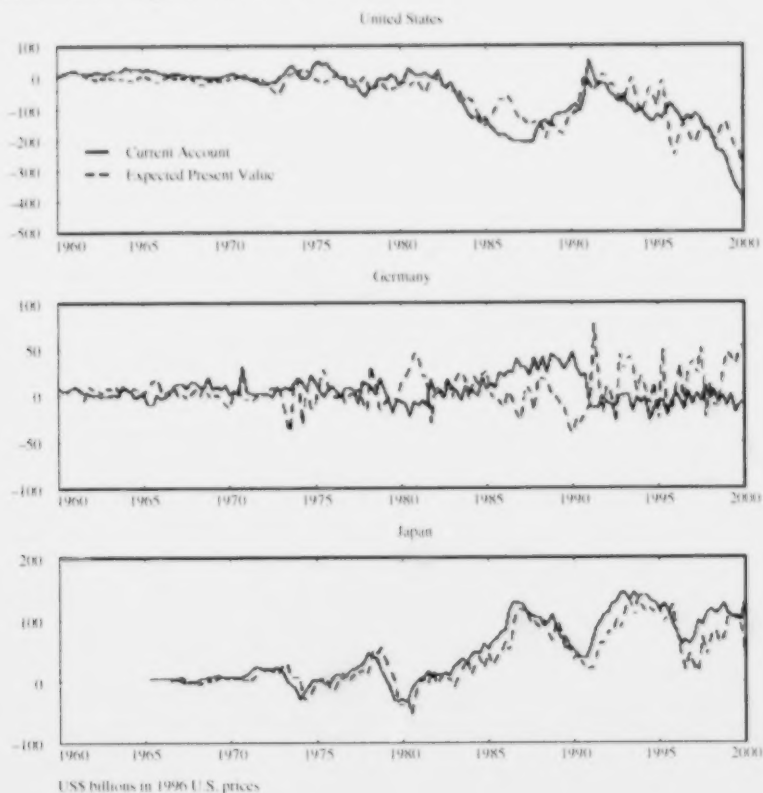


Table 1
The current account and future movements in relative net income

Country	Current account surplus	Average relative net income change
	1989:4	1990-2000
United States	-111.32	10.08
Germany	35.45	-9.01
Japan	55.92	-5.30

Notes: 1996 U.S. prices. Net income change compared to country average.

theory predicts that the German current account should have been more volatile than it was.

Overall, while it is statistically rejected, the intertemporal approach appears able to frequently match broad movements in the current account based on forecasted movements in relative net income, although it is not always able to match the exact magnitudes or timing of swings in these two variables. New open-economy models that allow for current account deficits in equilibrium hold the promise of enriching the intertemporal approach in several empirically relevant ways while also keeping some of its original insights into current account dynamics. Where the original approach did not allow for exchange rate effects on expenditure or for investment or intermediate good imports, as discussed in section 2.1.2, recent papers have begun to explore these issues in serious ways, although often in contexts in which current account dynamics are shut down. Several of these papers have begun to explore ways to allow for current account dynamics while maintaining a unique steady state that can be linearized around. Ghironi (2002), Cavallo and Ghironi (2002), and Smets and Wouters (2002) incorporate Blanchard-Yaari-type overlapping generations into their models. Benigno (2001a) and Kollmann (2001) instead maintain a unique steady state by assuming an exogenously specified risk premium that depends on net foreign asset positions. This line of work should eventually lead both to better models of the current account and to a better understanding of the extent to which monetary policy should depend upon the current account.

3 How Should Monetary Policy React to Exchange Rate Movements?

3.1 The implications of producer currency pricing

A number of papers have demonstrated environments featuring PCP in which the optimal monetary policy continues to target domestic variables even in an open-economy context. This work includes Gali and Monacelli (2002); Clarida, Gali, and Gertler (2001a); and Engel (2002), who all explicitly assume that international financial markets are complete, as well as Corsetti and Pesenti (2001b) and Sutherland (2000, 2002a), who assume a unitary elasticity of demand between domestic and foreign goods and separability of tradables consumption so that the equilibrium is identical to one in which financial markets are complete.

The economics of this result can be fairly easily demonstrated. To simplify notation, we follow what has become a standard parameterization of the utility function (6) by assuming that $\rho = \epsilon = \nu = 1$. Under PCP, a profit-

maximizing domestic firm that must set its price one period in advance will set its price in domestic currency equal to the expected value of equation (4),

$$\bar{p}(z) = \left(\frac{\theta}{\theta - 1} \right) E_{t-1}(\kappa_t w_t). \quad (26)$$

Because firms are identical, all domestic firms set the same price and $P_h = \bar{p}(z)$. Likewise $P_f = e\bar{p}^*(z)$. Following Corsetti and Pesenti (2001a) in assuming that the consumption bundle is Cobb-Douglas as in equation (11), the domestic price index is

$$\begin{aligned} P &= P_h^\gamma P_f^{1-\gamma} \\ &= \left(\frac{\theta}{\theta - 1} \right) [E_{t-1}(\kappa_t w_t)]^\gamma \left[E_{t-1}(\kappa_t^* w_t^*) \right]^{1-\gamma}. \end{aligned} \quad (27)$$

Since the papers in question all effectively shut down movements in the current account, the result in question can be shown either in a static or dynamic setting without material effect. For simplicity we choose the static setting, which has the effect of simplifying equation (8) for money demand to

$$\frac{M_t}{P_t} = \chi^{\frac{1}{\varepsilon}} C_t^{\frac{\rho}{\varepsilon}}. \quad (28)$$

It is standard in this literature to evaluate welfare while ignoring the effects of real money balances on utility—that is, treating the parameter χ as if it were infinitesimal. Ignoring effects on real balances, there are two sources of economic distortion in this model: sticky prices and the markup charged by firms. Under the assumption that monetary policy cannot affect the distortions associated with firm's market power, the constrained Pareto optimum is to replicate the equilibrium under flexible prices. Comparing expected utility under sticky prices with expected utility under flexible prices is therefore the relevant loss function for the monetary authority,

$$\begin{aligned} L &= E_{t-1}(U) - E_{t-1}(U^{flex}) \\ &= E_{t-1}(\ln C) - E_{t-1}(\ln C^{flex}) \\ &= \gamma E_{t-1} \left(\ln \frac{\kappa_t w_t}{E_{t-1}(\kappa_t w_t)} \right) + (1 - \gamma) E_{t-1} \left(\ln \frac{\kappa_t^* w_t^*}{E_{t-1}(\kappa_t^* w_t^*)} \right). \end{aligned} \quad (29)$$

The monetary authority wishes to minimize a weighted average of deviations of domestic and foreign producer currency prices from their flexible-price values. Under PCP, however, domestic monetary policy will only affect domestic producer currency prices—any movement it causes in the exchange rate will have no effect on foreign producer prices denominated in foreign currency because of the assumption of complete pass-through of exchange rate movements. Hence, the monetary authority should target domestic prices, P_h , and attempt to stabilize them at the flexible-price equilibrium level.¹² Under the assumed parameterization $w_t = M_t$, the best that the domestic monetary authority can do is to choose a monetary policy that sets marginal cost to a constant,

$$M_t = \frac{\text{constant}}{\kappa_t}.$$

This result is exactly what the monetary authority would attempt to do in a closed economy (where $\gamma = 1$) and, furthermore, if both monetary authorities adopt this policy then the fixed-price equilibrium will exactly replicate an equilibrium with flexible prices, leading to a constrained optimum. Tille (2002) points out that this result may not hold if there are sectoral shocks rather than country-specific shocks. Movements in the exchange rate change the relative price of goods across countries, but this will cause intrasectoral distortions if sectoral production occurs across countries.

The work of Obstfeld and Rogoff (2002) helps shed light on when the optimality of domestic stabilization should be expected to hold. Obstfeld and Rogoff introduce non-traded goods into the Cobb-Douglas formulation of the consumption index. If utility is separable between tradables and non-tradables (which occurs if $\rho = 1$ in this context) then, as discussed earlier, the equilibrium is identical to one in which markets are complete. If utility is non-separable ($\rho \neq 1$), then the equilibrium will differ from the complete markets outcome, and this introduces another source of economic distortion into the economy. Because movements in the exchange rate can affect this distortion by shifting wealth between foreign and domestic consumers and thereby move the economy closer to an optimum, the monetary authority will no longer desire to target domestic prices alone. Obstfeld and Rogoff

12. This mirrors the result in Aoki (2001) who, in a closed economy setting, models two sectors, one with flexible prices and the other with sticky prices, and finds that optimal policy will target inflation in the sticky-price sector. Aoki informally argues that his result would imply targeting domestic prices in an open-economy setting with flexible exchange rates, as is confirmed in the latter papers we have cited. Benigno (2001b) looks at a single central bank setting policy for two countries, each with fixed- and flexible-price sectors.

conclude that the welfare benefits of altering monetary policy to take this effect into account are small in their model, but it is possible that it may be larger in other contexts.¹³ It is important to note that the result is not affected by simply adding any source of distortion. Galí and Monacelli (2002) and Clarida, Galí, and Gertler (2001a) both assume that the price-setting is staggered based on the Calvo price-setting model. Staggering introduces another source of distortion by causing suboptimal variation in prices across firms. Clarida, Galí, and Gertler (2001a) further introduce frictions in wage-setting that may distort the real wage from its competitive level. However, because both types of distortion are purely domestic, neither alters the prescription that the monetary authority should target domestic variables under PCP pricing.

Obviously the assumption that real balance effects can be ignored plays a role in this result. If χ is non-negligible, then the monetary authority will also have to balance distortions to real money holdings caused by inflation. However, CPI inflation rather than domestic inflation alone affects money demand, and this implies that the monetary authority should target some weighted average of domestic and CPI inflation. Svensson (2000) emphasizes that monetary authorities may wish to explicitly include the exchange rate in their reaction function because exchange rate movements are likely to affect CPI inflation more quickly than domestic disturbances.

3.2 Incomplete pass-through

Several papers have begun to explore the extent to which incomplete pass-through affects the PCP prescription that monetary authorities should target domestic variables. This work includes Devereux and Engel (2000), Corsetti and Pesenti (2001b), Sutherland (2002a), Engel (2002), and Smets and Wouters (2002). These papers conclude that incomplete pass-through does in fact give the monetary authority an incentive to react to the exchange rate.

Following Corsetti and Pesenti, this result can be seen by generalizing the framework just presented to one in which import prices partially react to exchange rates:

13. Obstfeld and Rogoff's parameterization links the degree of risk aversion to the degree of non-separability between traded and non-traded goods. In theory, these may be distinct—for example, Corsetti and Dedola (2002) assume that non-traded distribution services must be combined with traded goods in fixed proportion in final consumption, so that the degree of non-separability is high while the degree of risk aversion is free to vary.

$$P_f = \left[\int_0^1 (e^{1-s} \bar{p}^*(z))^{\frac{1}{1-\theta}} dz \right]^{1-\theta}, \quad (30)$$

where $\bar{p}^*(z)$ is the fixed foreign currency price of imports. Note that $s = 0$ represents full pass-through (PCP) and $s = 1$ represents zero pass-through (LCP). As before, in equation (26), producers will set prices in their home market to equal a fixed markup over expected home marginal cost. In setting export prices, however, it will take into account the effect that exchange rate movements have on its revenue in terms of its home currency. With incomplete pass-through, firms will wish to set different prices in the two markets. Corsetti and Pesenti show that in equilibrium, foreign firms will set

$$\bar{p}^*(z) = \left(\frac{\theta}{\theta-1} \right) E_{t-1} (e^s \kappa_t^* w_t^*). \quad (31)$$

As emphasized also by Bacchetta and van Wincoop (2000), Corsetti and Pesenti make the point that incomplete pass-through can raise export prices by causing foreign firms to charge a risk premium to compensate for exchange rate risk. If the exchange rate varies positively with foreign marginal costs, foreign firms will charge a higher price for their exports, reducing welfare for the domestic residents who import them. The domestic loss function in this case becomes

$$L = \gamma E_{t-1} \left\{ \ln \frac{\kappa_t w_t}{E_{t-1}(\kappa_t w_t)} \right\} + (1-\gamma) E_{t-1} \left\{ \ln \frac{e^s \kappa_t^* w_t^*}{E_{t-1}(e^s \kappa_t^* w_t^*)} \right\}. \quad (32)$$

Because the domestic monetary authority can affect the variability of the exchange rate and hence potentially lower the risk premium charged on domestic imports, it should no longer target the domestic price level only. Corsetti and Pesenti show that as s increases, the monetary authority will place an increasing weight on exchange rate stabilization. In a quite ambitious paper, Smets and Wouters (2002) fit a linearized version of this type of model of the euro area and conclude that under their estimated degree of pass-through, the welfare-optimizing monetary policy would target both domestic and import price inflation. In a similar framework, Sutherland (2002a) also concludes that the monetary authority will wish to include exchange rate movements in its target, but surprisingly finds that if labour supply is sufficiently inelastic, the monetary authority may wish to increase exchange rate variability rather than decrease it. The trade-off is that while exchange rate variability will cause a higher price for domestic imports, lowering the amount of imports in domestic consumption, it will

also decrease the amount of domestic goods sent for export, potentially leaving more for domestic consumption. If domestic labour supply is inelastic, this latter effect may predominate.

Devereux and Engel (2000) and Engel (2002) examine the case of full LCP and demonstrate that a co-operative fixed exchange rate regime can support the constrained optimum in their models. In the flexible-price equilibrium, the terms of trade will optimally fluctuate in response to country-specific shocks, allowing expenditure to shift towards goods that have lower marginal costs of production. Under full LCP, this expenditure-switching effect is completely shut down, because both domestically produced and imported goods prices are fixed in the short run and unresponsive to movements in the nominal exchange rate. The exchange rate will still affect capital flows, however. With complete risk-sharing (due either to a complete set of international financial markets or to a unitary elasticity of demand for domestic and imported goods and separability in traded consumption), domestic and foreign households will share risk by equating the marginal utility of one unit of home currency to domestic consumers with its marginal utility to foreign consumers in any state of nature:

$$\frac{1}{P} C^{-\rho} = \frac{1}{e P^*} (C^*)^{-\rho}. \quad (33)$$

At an optimum, domestic and foreign tradables consumption should be perfectly correlated. Under LCP, both P and P^* are fixed; hence, any movements in the exchange rate will drive a wedge between domestic and foreign tradables consumption and lead to a suboptimal outcome. Devereux and Engel show that the best that monetary authorities can do is to keep the exchange rate fixed. This policy will not replicate the flexible-price equilibrium, but will lead to the best outcome possible under LCP.

This result obviously makes great use of the assumption of complete risk-sharing. It is an open question if it must be significantly modified when risk-sharing is incomplete. Obstfeld and Rogoff (1995a) originally emphasized the permanent effects of monetary policy caused by shifts in wealth and the current account. In an incomplete market, setting the ability of monetary policy to effect cross-country shifts in wealth may be a welfare-improving tool.

4 Policy Coordination

Central banks are concerned not only with how to react to domestic and international shocks, but also with how other policy-makers around the world will react to these same shocks. Monetary policy in one country may

have policy spillovers on other countries. For example, if monetary policy has "beggar-thy-neighbour" expenditure-switching effects through the exchange rate, then a country's monetary policy actions, although beneficial from its own point of view, may have negative spillovers on other nations. In a Nash equilibrium, each nation maximizes only its own welfare subject to the reaction of other nations. Spillovers, whether they be negative or positive, give each nation the incentive to change the monetary policy instrument either "too much" or "not enough" as they try to gain at the expense of the others. In this Nash equilibrium, all countries are worse off than in a co-operative equilibrium in which they jointly maximize their welfare and internalize the cost or benefits of the spillovers.

The topic of international policy coordination is one on which many insightful papers have been written over the past several decades.¹⁴ As of the late 1990s, there was reasonable consensus on several issues. First, there are potential gains from the coordination of fiscal or monetary policies as measured by the difference between a country's welfare function under the co-operative solution and under the Nash non-co-operative equilibrium, where each nation maximizes its own welfare. This result held both in the case of symmetric shocks (or global shocks, such as oil-price shocks) and perfectly asymmetric shocks. Second, empirical and calibrated estimates of the size of the gains to co-operation were deemed to be small, these being on the order of one-half of 1 per cent to 1 per cent of GDP per year.¹⁵ Third, the size of gains may be small because of the relatively low degree of integration among economies. As goods and financial market integration rise, spillovers between nations may also rise, leading to larger empirical gains from co-operation.

Recent papers by Obstfeld and Rogoff (2002) and others have generated renewed interest in the analysis of policy coordination. They contain results derived using the new open-economy macroeconomic model outlined above. While there is still no consensus on the gains from co-operation, the use of a micro-founded open-economy model has yielded several important insights. Welfare analysis can make use of the micro-foundations of the model with policy-makers maximizing the utility of the households, rather than an ad hoc loss function. Policy spillovers are therefore explicitly spillovers onto utility, rather than macroeconomic variables. The use of

14. Useful surveys of the older literature include Canzoneri and Henderson (1991), Persson and Tabellini (1995), and McKibben (1997). For a recent survey that explores the relationship between the theory and actual practice of international policy coordination, see Meyer, Doyle, Gagnon, and Henderson (2002).

15. McKibben (1997) extensively reviews the literature on the estimation of policy coordination gains. Meyer et al. (2002) argue that the gains found in this literature are somewhat larger than the consensus view would suggest.

micro-founded models has highlighted how distortions in the economy, such as monopoly power and imperfections in capital markets along with nominal rigidities, create channels for spillovers between nations. The focus on these spillovers has raised new questions about the role that integration might play in the size of gains from co-operation. It has also underscored that different spillovers, under certain conditions, may give policy-makers incentives to change policy in opposite directions and diminish the overall externality that creates the opportunity for co-operative gains. The role these new distortions play has also been linked to the currency pricing decisions of firms, how different sectors are affected by shocks, and what the elasticity of substitution is between different goods. Finally, the newer literature departs from the old by looking at monetary policy rules—so policy-makers are choosing reaction-function parameters once rather than choosing responses each period.

The first of these papers, Obstfeld and Rogoff (2002), claims that there are no gains to coordination under certain assumptions, and quite limited gains under a broader set of plausible assumptions. Yet the primary contribution of Obstfeld and Rogoff to international policy coordination is not the result that the gains are small. This bottom line is the same basic result of many papers in the earlier literature. Furthermore, subsequent papers (discussed below) will call that result into question, and much more work will need to be done to achieve any sort of a consensus, if indeed that is possible. Rather, as discussed above, the paper highlights that the same new channels by which changes in the monetary policy rule can affect the economy can work against one another.

Obstfeld and Rogoff (2002) extend their earlier model (2000) to address the gains to coordination, setting $v = \epsilon = 1$ in the expected utility version of equation (6). The authors rewrite the disutility-of-effort shocks so that they are similar to the symmetric and perfectly asymmetric shocks studied by the earlier coordination literature. Home, κ , and foreign, κ^* , disutility-of-effort shocks are used to create:

$$\kappa_w = \frac{1}{2}(\ln \kappa + \ln \kappa^*) \quad \kappa_d = \frac{1}{2}(\ln \kappa - \ln \kappa^*), \quad (34)$$

where κ_w is a symmetric (or world) disutility-of-effort shock, and κ_d is a perfectly asymmetric (or "difference") disutility-of-effort shock.

Policy-makers in this model face three kinds of relevant distortions.¹⁶ The first, of course, is sticky wages, the same distortion as in the older literature

16. The model also includes a terms-of-trade distortion, where either country could raise its own welfare by imposing an import tariff. See Obstfeld and Rogoff (2002) for a further explanation of why this distortion does not play a role here.

that enables monetary policy to have an effect on real variables in the economy in the short run. The second distortion is the monopoly power of workers that enables them to set wages higher than and to work less than the competitive level. Even when monetary policy is set according to a rule, *ex ante* a central bank can affect the level of nominal wages by affecting the level of risk facing workers. The third distortion is that markets may be incomplete, so that consumers in home and foreign countries can only imperfectly share risks, such as when households can trade only real bonds. Pre-commitment to a coordinated policy rule could help share risks across countries. For example, if the home country is faced with only a positive asymmetric disutility-of-effort shock (and foreign a negative one), $\kappa_d > 0$, $\kappa_w = 0$, then both home and foreign monetary policy can cause an appreciation of home's exchange rate, helping home purchase more of foreign's exports for fewer of home's exports.

To solve for the welfare gains to coordination, Obstfeld and Rogoff solve the model for home and foreign household utility in the limiting case when the utility gained from liquidity services goes to zero, $\chi \rightarrow 0$:

$$E(U) = \left(\frac{1}{1-\rho} - \frac{(\phi-1)(\theta-1)}{\phi\theta} \right)$$

$$\exp(1-\rho)E(x) + \frac{(1-\rho)(1-\gamma)}{2}E(\tau) + \frac{1-\rho}{2}\sigma_\epsilon^2 + \frac{(1-\rho)(1-\gamma)^2}{8}\sigma_\epsilon^2 + \frac{(1-\rho)(1-\gamma)}{2}\sigma_{\epsilon\tau} \quad (35)$$

$$E(U^*) = E(U) - (1-\gamma)E(\tau), \quad (36)$$

where $E(x)$ is the expected value of world tradables spending, and $E(\tau)$ is the expected terms of trade. One can start to see the possibility for spillovers by noticing that the expected terms of trade enters in home and foreign's utility functions with opposite signs. These potential spillovers may affect both the average levels as well as the variances of variables. For example, the expected terms of trade, $E(\tau)$, is lowered by an increase in the covariance of nominal exchange rates with the world disutility-of-effort shock, $\sigma_{\kappa_{we}}$. A higher $\sigma_{\kappa_{we}}$ will mean that home wages, set one period ahead of time, will be higher relative to foreign, since home's relative marginal utility of consumption will be low when home labour supplies and world marginal disutility of effort are high.

Before any other agents act, the monetary authority commits to a monetary policy rule where the money stock of each nation is a function of the disutility-of-effort shocks:

$$\hat{m} = -\delta_d \hat{\kappa}_d - \delta_w \hat{\kappa}_w, \quad (37)$$

where m is the logarithm of the money stock and, in contrast to section 2.1.2, carats or hats (^) over variables now denote surprise components, e.g., $\hat{\kappa}_d = \kappa_d - E\{\kappa_d\}$. So, in the Nash solution, for example, the home country maximizes expected utility by choosing δ_d and δ_w , subject to its own monetary policy rule and the reaction coefficients of the foreign country. In the co-operative case, the countries jointly maximize a weighted average of their utilities,

$$E(V) = \frac{1}{2}(E(U) + E(U^*)), \quad (38)$$

by choosing δ_d , δ_w , δ_d^* , and δ_w^* , again subject to the form of their monetary policy rules.

Even though households cannot trade contingent securities, when households derive utility from the logarithm of consumption and there is a unitary elasticity of substitution between home and foreign tradable goods, tradables consumption at home and abroad will be equal in all states of nature. In other words, although there is no trade in contingent securities in this model, the economy will behave similarly to the case where markets are complete and our third distortion disappears. In this case, where $\rho = 1$, both home and foreign monetary policy are the same in the co-operative solution as they are in the Nash equilibrium. The result comes about because the utility effects of the two remaining distortions, those due to sticky wages and monopoly power, are separable and cannot be affected by a commitment monetary policy.¹⁷ When $\rho = 1$, home's utility function (equation (35)) reduces to

$$E(U) = E(x) + \left(\frac{1-\gamma}{2}\right)E(\tau) - \text{constant}. \quad (39)$$

Expected utility under co-operation (equation (38)) reduces to

$$E(V) = E(x) + \text{constant}. \quad (40)$$

In both cases, nations care about the expected world value of spending on tradables, x . Even though the terms of trade enters into the two non-co-operative utility functions in opposite directions, the logarithmic form of consumption and unitary elasticity of substitution between home and foreign tradables has strong implications for each nation's behaviour. As outlined above, these assumptions also ensure that the current account remains in balance. In reaction to a perfectly asymmetric increase in the

17. Corsetti and Dedola (2002) show that when markets are competitive, the Obstfeld and Rogoff result still holds.

marginal disutility of effort only, $\kappa_d > 0$, $\kappa_w = 0$, the home central bank will decrease the money supply (and foreign will loosen), appreciating the home currency. Home workers will want to work less, so the home policy-maker's tightening will shift work away from home towards foreign, while at the same time increasing home's purchasing power, keeping consumption and the utility of work effort at the same level that would prevail in the absence of the shock. The important point is, as Obstfeld and Rogoff show, this non-co-operative outcome will replicate the equilibrium when prices are flexible for both countries and hence each nation has no incentive to deviate from it. In other words, under these conditions there are no policy spillovers.

In the case where $\rho \neq 1$, the economy no longer mimics the case of complete markets, and the marginal utility of tradables consumption depends on the consumption of non-tradables. When $\rho > 1$, as is more plausible, non-co-operative policy-makers will react less than is optimal when faced with an asymmetric increase in the marginal disutility of effort. When home commits to tighten the money supply in response to positive κ_d shocks, non-tradable production will suffer as well as tradable. Since the marginal utility of tradables consumption depends positively on non-tradable consumption, home will not want to contract as much as it did when the utilities of consumption were separable. Both countries could gain by co-operating and reacting more to the shock, since it would shift more production from the home to the foreign country. There will be gains to co-operation as each country can at least partially insure the other against asymmetric disutility-of-effort shocks. In the face of a perfectly asymmetric increase in home's disutility of effort, foreign can loosen and home tighten its money supply more than is nationally optimal, and consequently increase welfare in both countries.

Obstfeld and Rogoff conduct simulations of the model to demonstrate that the gains when $\rho \neq 1$ are relatively small—thousandths of a per cent of output—and are dwarfed by the gains to stabilization, except at an implausibly high level of risk aversion, $\rho > 100$. Furthermore, the gain from coordination relative to the gain from stabilization decreases as ρ gets closer to 1 from above. Since the gains are zero only at $\rho = 1$, when the model replicates the complete markets outcome for consumption, Obstfeld and Rogoff conclude that the gains to coordination become smaller as economies become more integrated.

Also, in contrast to the earlier literature, Obstfeld and Rogoff show in their model that there are no gains to co-operation when there are only global disutility-of-effort shocks, $\kappa_d = 0$, $\kappa_w > 0$, even when $\rho \neq 1$. Under a global shock to both sectors, without co-operation the monetary authority can still replicate the equilibrium when prices are flexible, because of the

separability of the monopoly and sticky-wage distortions. When $\rho \neq 1$, since the two countries are symmetric, any risk-sharing is precluded because a global shock affects them equally.

Subsequent papers have shown that three of these results may depend on particular assumptions. First, as Corsetti and Pesenti (2001b) show, interestingly enough, with only partial indexation of prices to exchange rates, there will be gains to international co-operation. The authors introduce a term into an extension of an earlier version of their own model that measures the degree of pass-through. With complete pass-through, they can demonstrate the Obstfeld and Rogoff result that there are no gains to co-operation in response to an asymmetric shock in the disutility of effort when $\rho = 1$. With no pass-through, Corsetti and Pesenti also conclude that there are no gains, because now there are no policy spillovers. They do not assess the size of the gains in the intermediate case.

Second, Canzoneri, Cumby, and Diba (2002) show that if there is no longer a uniform effect of the shock across sectors, there are gains to coordination when economies are hit by a common shock. While such a shock is no longer strictly a global shock in the same sense as in the earlier literature, this fact in no way diminishes its importance. Canzoneri, Cumby, and Diba motivate differences in the sectoral responses by appealing to the possibility of differences in productivity across sectors. For example, the literature on the Balassa-Samuelson effect suggests that there are productivity differences across traded and non-traded sectors. The authors also appeal to differences in the degree or type of nominal rigidities across sectors. In light of work by Erceg, Henderson, and Levin (2000), they suggest that decentralizing production and introducing an asymmetry in price stickiness across sectors can lead to a policy trade-off even when shocks are global. The authors look at three additional extreme cases, each of which gives increasingly larger gains: (i) when there are only shocks to the tradable goods sector and none to the non-tradable goods sector; (ii) when there are only shocks to the non-tradable goods sector and none to the tradable sector; and (iii) when there are only shocks to the export sector. Under their parameterization, the authors claim that the first case yields gains to coordination that are on the same order as those found in the earlier literature, while the other two cases yield gains that are larger and more significant.¹⁸

18. Clarida, Gali, and Gertler (2001b) also show that there are gains to coordination in the face of cost-push shocks.

Finally, according to Sutherland (2002b),¹⁹ changing the model so that agents are allowed to trade contingent contracts after the central banks choose their monetary policy rule challenges the Obstfeld and Rogoff claim that increasing financial integration actually decreases the gains from coordination. Sutherland shows that another important assumption to relax is that of a unitary elasticity of substitution between home and foreign tradable goods.²⁰ Instead, Sutherland assumes tradable consumption follows equation (9), where $\gamma = 1/2$ and where $\phi \geq 1$. When the utility of consumption is logarithmic, $\rho = 1$, and the elasticity of substitution between home and foreign tradables is greater than one, $\phi > 1$, Sutherland shows that there are tiny gains to co-operation when agents cannot share risk. When they can share risk, however, there are larger, but still small (tenths of a per cent of steady-state consumption) gains. These gains are even larger when $\rho > 1$, and we move from financial autarky to risk-sharing, with absolute gains rising to around 1 per cent of steady-state consumption with risk-sharing. While larger in absolute terms, these gains are comparable to those estimated by the earlier literature. Nonetheless, the relative gains of co-operation under risk-sharing compared with the gains to stabilization are substantial. The reasons for these gains are twofold. First, with the ability to trade a full set of contingent contracts, home and foreign consumption are now equal in every state. Second, with $\phi > 1$, the potency of the expenditure-switching effects of monetary policy is increased. An increase in home's marginal disutility of effort will give home an incentive to shift output from home to foreign, with a smaller consequence for its own consumption than under financial autarky. Changing ϕ , financial integration, or ρ individually, has only small effects, but changing all three produces larger gains. These possible gains increase as households become more risk-averse.²¹

This more recent literature in policy coordination is still composed of relatively few papers and as such has not picked up a host of issues that the earlier and more extensive literature tried to address. These new papers focus primarily on the gains from co-operation when the central bank can commit to a monetary policy rule (such as equation (37)) both in the Nash and the co-operative equilibria. Because of these rules, it is not important to

19. Sutherland (2002b) also explores the possibility of allowing agents to sign contingent contracts before monetary policy-makers set their rules. Under this second form of risk-sharing, the potential gains to international policy coordination are even larger. Devereux (2001) and Benigno (2001a) also look at the role of financial market structure in policy coordination.

20. Benigno and Benigno (2001) also look at this important case.

21. Sutherland arrives at his solutions by using a second-order approximation of the welfare function. He outlines the technique in Sutherland (2002b).

look at any more than a one-shot game, and the co-operative equilibrium is assumed to be enforceable. The earlier literature, in contrast, looked at equilibria where central banks still had discretion, and thus, also explored ways in which co-operation might be supported, such as by reputational equilibria in repeated games.²² Other earlier work explored the role of information, for example, looking at the role that model uncertainty and information exchange played in calculating the gains to policy coordination.²³ A few earlier papers sought larger gains to coordination by comparing equilibria other than the co-operative and conventional non-co-operative outcomes. For example, Canzoneri and Edison (1990) find larger gains to coordination by comparing a non-co-operative outcome where the two countries have correct information about the size of economic variables to a non-co-operative equilibrium where the countries are making decisions based on a estimate. One of the challenges of the new literature is to use the advantages of the more micro-founded framework to address some of these issues while not becoming weighed down by the difficulties of the model.

Even when there are gains to co-operation, it is not clear that international policy coordination must involve countries making explicit agreements. In the earlier literature, authors argued that since countries will repeatedly face situations where there are gains to co-operation, then even when they have discretion, the possibility or threat of lower welfare in the future will help to support co-operation today. The recent literature assumes that central banks decide on policy rules that will hold for the foreseeable future. It is not unreasonable to believe that rational central banks that are committing to actions into the future will choose policy rules that will enact the co-operative solution and improve their welfare. Furthermore, there is a belief by some that central banks may not in practice face a time-consistency problem over domestic inflation expectations—either because of the belief that central bankers do not have output-gap targets that are “too high” or because central bankers understanding the problem can resist temptation. Modelling central bank behaviour as a policy rule assumes away this time-consistency problem. It may also not be unreasonable to believe that policy-makers may have an incentive to enact something approximating globally optimal policy without the need for explicit agreements.

22. See Canzoneri and Henderson (1991).

23. See Ghosh and Masson (1994).

Conclusions

In his 1993 Graham lecture, Paul Krugman laid out four challenges that represented not only important problems facing open-economy macroeconomics, but constraints on our ability to give useful advice to policy-makers. First, he felt we needed an open-economy macroeconomic model with nominal rigidities that we could integrate with modern trade theory. Second, we required a sticky-price open-economy macroeconomic model that also took an intertemporal approach to the current account. Third, we needed to incorporate into our macroeconomic models expectations that "made sense," particularly to help explain the behaviour of asset markets. Finally, we needed a better understanding of the microeconomics of using a common currency.

Almost a decade later, while we have not solved all of the field's great mysteries, open-economy macroeconomics has made at least some progress in each of these areas, and holds great promise in understanding more. We now have general-equilibrium multi-country models with nominal rigidities that have monopolistically competitive firms and international trade. We have models with intertemporal utility-maximizing agents that also have sticky wages or prices. We have stochastic models where there is a link between variances and covariances and the levels of macroeconomic variables, including the exchange rate. And we have models where the economy's response to monetary policy and monetary policy-makers' optimal reaction to movements in the exchange rate depend on such things as the preferences of households and the degree of pricing to market. All of these advances have increased our understanding of the effects of monetary policy.

This body of work lays out an important framework for answering normative questions such as what variables monetary policy authorities should react to in an open economy, and whether there are gains to central banks co-operating. Many unanswered questions remain, however. The results of the existing literature depend very much on the functional form and parameter values of the models' elements and often involve assumptions that shut down current account dynamics. While there have been several excellent papers that try to estimate or calibrate more realistic forms of these models, such as Bergin (2003) and Ghironi (2000), further work in this area is needed. We hope that not only will these models continue to yield a better understanding of the open macroeconomy, but that they will also lead to new empirical insights by helping to show us where to look.

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Discussion

Frank Smets

The paper by Bowman and Doyle provides a useful and comprehensive survey of the recent literature on the so-called New Open-Economy Macroeconomics (NOEM), following the seminal work by Obstfeld and Rogoff (1996). The NOEM was developed in parallel with its closed-economy counterpart, which has been labelled New Neoclassical Synthesis, Neo-Wicksellian, or New Keynesian by Goodfriend and King (1997), Woodford (2003), and Clarida, Gali, and Gertler (1999), respectively. The common distinguishing features of both research programs are: (i) a general-equilibrium set-up; (ii) structural macroeconomic relationships based on micro-foundations; and (iii) the introduction of monopolistic competition in goods and labour markets with sticky nominal prices or wages.

The advantages of working with this class of macro models for monetary policy analysis are threefold. First, because of the micro foundations, the use of those models for policy analysis is less subject to the Lucas critique. At a minimum, an explicit discussion of the structural parameters and shocks ensures that the modeller has a better sense for which parameters are likely to be policy-invariant. Second, the utility of the households in the economy provides a consistent welfare criterion for policy analysis. Third, the micro-foundations of the reduced-form parameters and shocks facilitate calibration and estimation. This is particularly useful when samples are short because of, for example, regime changes. Historically, there have also been differences in emphasis between the NOEM and its closed-economy counterpart. Because of its focus on cross-country interactions, the NOEM has had a comparative advantage in analyzing multi-sector models. There was initially a dominant use in the NOEM of one-period price and wage stickiness, which facilitated the theoretical analysis but came at the cost of limited empirical plausibility. And finally, there have been fewer attempts at

bringing the NOEM models to the data. One exception, however, is the work by Bergin (2003). The survey by Bowman and Doyle reflects some of those differences and is complementary to and more up-to-date than recent surveys by Lane (2001) and Sarno (2001).

Rather than add to the survey part in this discussion, I will illustrate the usefulness of the micro-founded approach that underlies the NOEM by addressing two important questions for monetary policy in an open economy. How do exchange rate shocks affect a small open economy? What price index should the monetary authorities target in an open economy? These questions will be addressed using the NOEM-style model developed in Smets and Wouters (2002), which incorporates Blanchard-Yaari households and monopolistic competition and sticky prices in domestic and imported goods markets. I will end my discussion with one area in which the NOEM needs to be strengthened: the theory of exchange rate determination.

1 How Do Changes in the Exchange Rate Affect a Small Open Economy?

The simple NOEM model developed in Smets and Wouters (2002) provides a relatively rich answer. In this model, exogenous changes in the exchange rate affect both the demand and supply sides of the economy. As is common in more traditional open-economy models, an increase in the terms of trade leads to expenditure switching from domestic to foreign goods, reducing the demand for domestic goods. This negative demand effect provides a rationale for the use of monetary conditions indexes (MCIs) to measure changes in the stance of monetary policy. The relative weight on the exchange rate in MCIs typically depends on the elasticity of demand with respect to changes in the exchange rate. However, an improvement in the terms of trade also leads to increased real consumption through its positive effect on real wealth, as the relative value of domestic production increases. This positive demand channel will tend to partially offset the negative effect discussed above.

A common feature of the NOEM models is that they also have a well articulated supply side. Again, an exchange rate appreciation has two supply effects in the Smets and Wouters model. An increase in the price of domestic goods relative to imported goods reduces producer wages for given consumption wages and thereby reduces the real marginal cost of domestic goods producers. This has a positive effect on the supply of domestic goods. Higher consumption, however, reduces the marginal utility of an additional unit of consumption and leads workers to reduce their supply of labour. This will tend to push up real wages and also has a negative effect on the supply

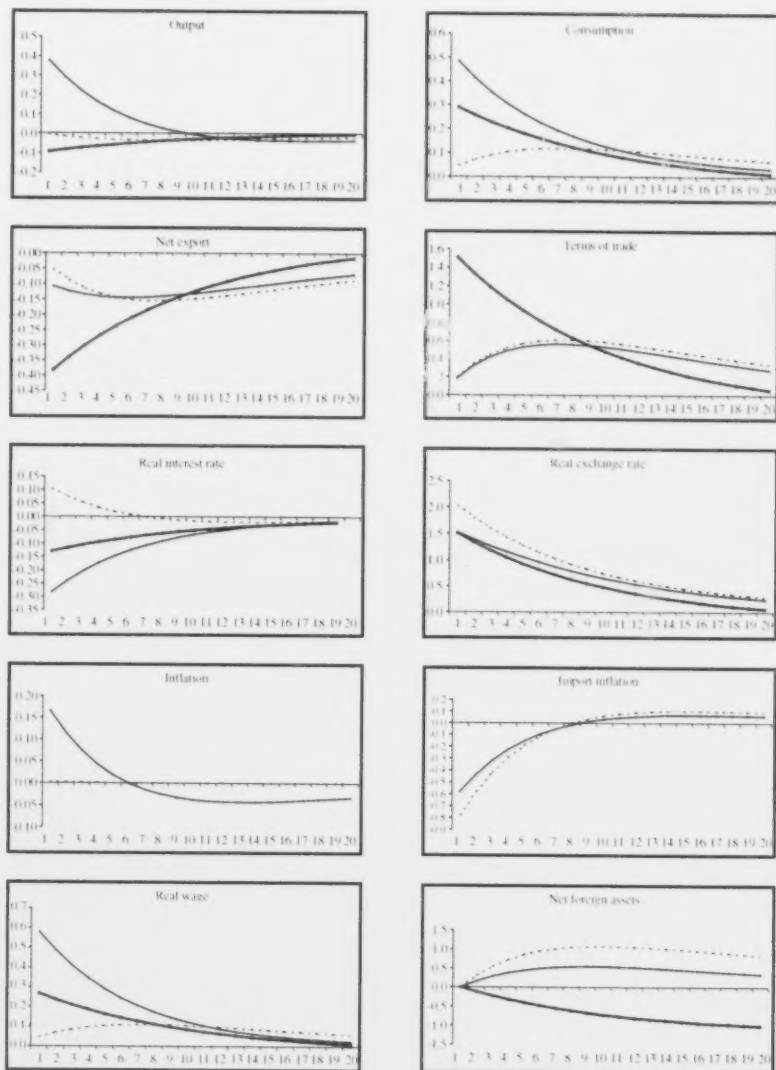
of domestic goods. Which of these two supply effects dominates will depend on the intertemporal elasticity of substitution.

Figure 1 illustrates the effect of a 0.2 percentage point fall in the foreign exchange risk premium in a version of the Smets-Wouters (2002) model calibrated to the euro area. A number of observations are worth making. First, under this calibration, the net supply effect appears to be negative as the flexible price level of output falls slightly (thick solid line in Figure 1). Second, with sticky domestic and imported goods prices, the response of the economy will depend on the monetary policy regime. When the central bank targets consumer price inflation (thin solid line in Figure 1), an appreciation of the exchange rate leads to a fall in import price inflation, but to a rise in domestic inflation. The positive consumption effect of the exchange rate appreciation dominates the negative effect on net exports, creating a positive domestic output gap. The policy implication of this simulation is important: if the central bank wants to stabilize domestic goods price inflation, then the real interest rate will have to rise to close the domestic output gap. While these particular results obviously depend on the specific model and its calibration, the analysis can potentially explain why empirically the exchange rate pass-through to consumer prices is generally very limited.

2 What Price Index to Target?

Should the monetary authorities in an open economy target consumer prices or producer prices? In the closed-economy model of Woodford (2003), price stickiness provides a rationale for stabilizing domestic inflation, because stable prices minimize the costs of inefficient resource allocation among otherwise identical sectors. Moreover, Woodford also shows that in the absence of cost-push shocks, there is no trade-off between output gap stabilization and price stability. As shown by Erceg, Henderson, and Levin (2000) and Benigno (2001), a trade-off generally arises when there are two sectors with different degrees of price rigidity. In that case, however, targeting a weighted average of inflation in the two sectors, where the weight depends on the degree of price stickiness, will be close to optimal. A similar result can be obtained in the open-economy set-up discussed above. Smets and Wouters show that targeting consumer prices (rather than domestic goods prices) will be close to optimal when the degree of price stickiness in domestic goods and imported goods markets is similar.

Figure 1



Notes: The thick solid line corresponds to the response of the flexible-price economy; the thin solid line corresponds to the sticky-price economy with optimal discretionary policy; and the broken line corresponds to the sticky-price economy with domestic inflation targeting.

Source: Smets and Wouters (2002).

3 The Theory of Exchange Rate Determination

One of the areas in international finance that receives very little attention in the survey of Bowman and Doyle is the theory of exchange rate determination. To some extent, this can be explained by the fact that the NOEM does not have much new to say about the issue. The exchange rate is typically determined by an interest rate parity condition, which often in combination with purchasing-power parity (PPP) implies a monetary model of exchange rate determination. Historically, these theories have not been very successful in explaining the empirical behaviour of the exchange rate. This lack of success is emphasized by Devereux and Engle (2002) who focus on the various modelling features that are necessary to explain the empirical disconnect between the exchange rate and its macroeconomic fundamentals.

Recent developments in the NOEM literature appear to point to three directions, which could lead to an improvement of the NOEM to better capture and explain exchange rate movements. First, as emphasized by Corsetti and Dedola (2002), transportation and distribution costs are important features of the international economy that can drive a wedge between exchange rate movements and the economy's fundamentals. Second, more work needs to be done on analyzing stochastic models and their implications for how risk premiums interact with the macroeconomy. One example of this work is Obstfeld and Rogoff (1998). Third, there is a need to integrate micromarket-structure theories that can explain the correlation between order flows and exchange rates in the NOEM (see, for example, Lyons 2001 and Hau and Rey 2003).

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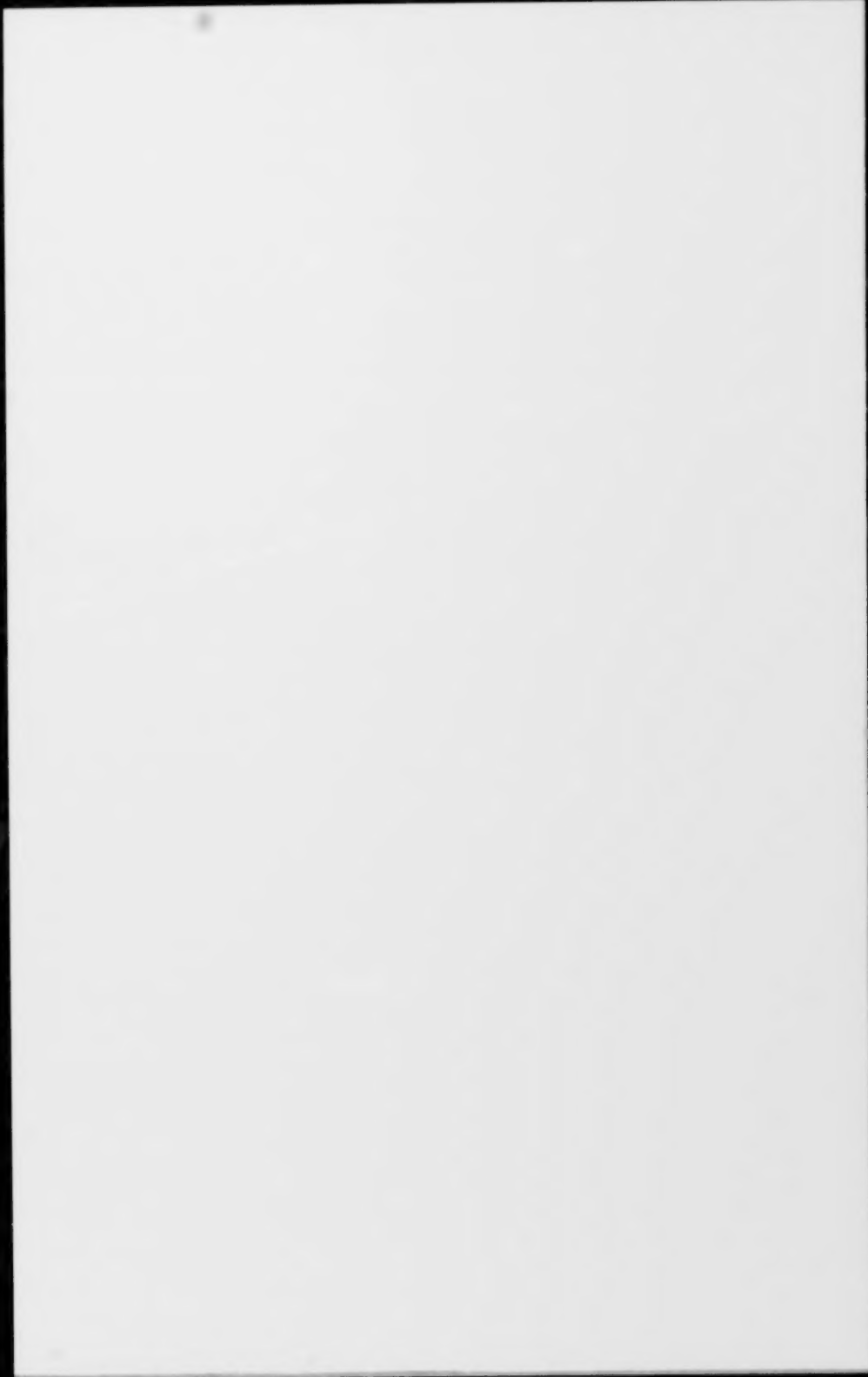
General Discussion*

One theme that arose during the discussion concerned the implications of real rigidities, such as distribution costs, limited participation, and cross-border shipping for exchange rate determination and the design of optimal monetary policy. Allen Head remarked that one of the challenges facing the developers of empirically satisfactory open-economy models is relaxing the tight relationship they generally predict between relative consumptions and real exchange rates. He then asked whether new approaches emphasizing distribution costs or limited participation may have implications for monetary policy analysis in a small open economy, or whether they are more likely to contribute to understanding exchange rate determination. In response to this, Brian Doyle suggested that the introduction of distribution costs into New Keynesian open-economy models may have implications for monetary policy by explaining the disconnect of exchange rate pass-through, which refers to the observed phenomenon whereby import prices respond considerably to exchange rate changes, while consumer prices respond minimally. Frank Smets added that recent research suggests that the incorporation of real rigidities associated with cross-border shipping of intermediate goods into small open-economy models can partially explain observed inflation and output persistence, a better understanding of which has obvious implications for the design of monetary policy.

The second principal theme that arose during the discussion concerned the implications of the persistence of shocks for the choice of pricing mechanism. Lawrence Schembri suggested that while New Keynesian open-economy models are derived from microeconomic foundations, they do not

* Prepared by Marjorie Santos and Francis Vitek.

feature microeconomic foundations underlying the choice between local currency pricing and producer currency pricing. He added that the literature on New Keynesian open-economy models originally emphasized the distinction between temporary and permanent shocks, and concluded that local currency pricing was probably optimal if all shocks were temporary, while if all shocks were permanent, then producer currency pricing would obtain in long-run equilibrium. In response to the suggestion that the recent literature has overlooked the persistence of shocks and their implications for the optimal pricing mechanism, Doyle noted that a number of recent papers have modelled the choice between local currency pricing and producer currency pricing as endogenous, and suggested that the literature is evolving in this direction.



Section 5: Price-Setting in a Small Open Economy



Monetary Policy in a Small Open Economy

Gabriel Srouf

Introduction

The past decade has seen widespread application of New Keynesian models to the study of monetary policy. These models are derived from first principles and provide a rigorous setting in which to re-examine conventional wisdom and well-known puzzles in economics. A number of authors have examined the special case of small open economies, but their results are typically formulated in general theoretical terms.¹ This paper applies the New Keynesian modelling approach to the context of the Canadian economy.

Canada is a small open economy with distinctive features; in particular,

- (i) it is highly dependent on a single large foreign economy;
- (ii) it comprises a significant primary goods sector geared largely to exports;
- (iii) its other traded goods sector (e.g., manufacturing) is highly integrated with the United States.

Following the global trend, the Canadian economy has become more open and integrated, both domestically and with the rest of the world. The volume of foreign trade in non-primary goods has grown substantially, while primary goods prices, and perhaps the size of that sector, have generally fallen. Labour mobility between sectors and across countries has increased, and the exchange rate pass-through may well have declined.

1. See surveys in Lane (2001) and Bowman and Doyle (2003).

Canada has pursued a flexible exchange rate regime since the early 1970s, and an inflation-targeting regime since 1991. While there is strong evidence that a flexible exchange rate has helped Canada to weather commodity price shocks, the persistent decline of the Canadian dollar and the increasing level of economic exchange between Canada and the United States, have led some economists to question the benefits of a floating exchange rate in the current environment.² Several authors have even argued that the current regime stifles productivity.

Accordingly, in this paper, we examine how some of the features of the Canadian economy might affect monetary policy and particularly the exchange rate. We ask whether past trends call for a less variable exchange rate other than through the direct effect of transactions costs.³

We develop a simple one-period model of a small open economy with nominal-wage rigidities, price-taking firms, and decreasing returns-to-scale technology. Similar models have been used in the literature, although the technology is usually assumed to have constant returns to scale, and firms are monopolistic-competitive and set their prices.⁴ We treat the equilibrium outcome that obtains if wages were perfectly flexible as a benchmark for an efficient monetary policy. For simplicity, we examine alternative cases separately,⁵ and focus on the monetary response to relative price shocks.

We first consider a one-sector case, whereby there is only one domestic and one foreign good, and all prices are set in the world market. We then show that the efficient monetary policy calls for a flexible exchange rate and conforms to conventional wisdom. Specifically, following a negative shock to the relative price of domestic goods, the local currency must depreciate and domestic prices rise, to counteract the rigidity of wages and emulate the drop in real wages that would have obtained if wages were flexible. In this case, monetary policy can reproduce the flexible-wage outcome.

We go on to examine a two-sector model. The goods in one sector are thought of as primary goods, the prices of which are set in the world market and exogenously given. The goods in the other sector are considered other traded goods (e.g., manufacturing) and have a relatively low elasticity of substitution with foreign (non-primary) goods. We consider the two extreme

2. See Courchene (1998), Harris (1993), Laidler (1999), and Murray (1999) for arguments on both sides of the debate.

3. For the effects of transactions costs, see Macklem, Osakwe, Pioro, and Schembri (2001).

4. See Devereux (2002) and Obstfeld and Rogoff (1999).

5. It is possible to describe one model that nests many cases. However, this unduly complicates the presentation and algebra. Moreover, the functional specifications in the extreme cases are more acceptable than a single artificial specification.

cases of perfect labour mobility and no labour mobility between the two sectors, as well as two cases where prices of non-primary goods are set in the world market and where they adjust endogenously to make demand and supply equal.

We show that, when labour is mobile, monetary policy can reproduce the flexible-wage outcome: as in the one-sector model, the domestic currency needs to depreciate following a negative shock to the relative price of primary goods. Output and employment in the domestic non-primary goods sector increase to take up the slack, and hence, if assumed endogenous, prices in that sector must fall relative to foreign goods. In this last case, higher economic integration, represented by a higher volume of international trade or higher elasticity of substitution between domestic and foreign (non-primary) goods, induces smaller currency depreciations. When labour is not mobile, it is shown that monetary policy cannot reproduce the flexible-wage outcome at the sectoral level, but it can reproduce the outcome at the aggregate level.

Finally, we again consider the one-sector model, but where firms are assumed to incur fixed costs in production along the same lines as described in Blanchard and Kiyotaki (1987). Aside from the literal interpretation, such fixed costs can also be thought of as a measure of a firm's degree of output efficiency. The presence of fixed costs means that, following negative shocks, some firms may not find it profitable to produce, and hence a portion of the economy's capacity may be left idle. Under these conditions, as long as some capacity remains idle, an improvement of the terms of trade would raise capacity utilization and output, but not necessarily the markup of domestic prices over wages. We then show that in this environment, monetary policy cannot always reproduce the flexible-wage outcome. In fact, in some circumstances, monetary policy may have to sustain production in inefficient firms, that is, in firms that would make negative profits in a perfectly flexible environment. In this sense, therefore, monetary policy can stifle productivity.

The literature on New Keynesian open-economy macroeconomics has usually focused on one-sector (albeit monopolistic-competitive) models. Two papers by Tille (1999, 2002) are noteworthy in relation to our work. As in our study, Tille (1999) examines the effect of the elasticity of substitution on exchange rate policy. Our work extends Tille's results in that we allow for two domestic sectors, and we examine the effect of a change in the elasticity of substitution between the goods in one sector and its foreign counterpart, keeping the elasticity of substitution between the two domestic sectors unchanged. Tille, on the other hand, considers one domestic sector and examines the effect of a country-wide change in the elasticity of substitution

between domestic and foreign goods. In contrast, Tille (2002)⁶ examines monetary policy in a two-sector model, but his focus is on the different implications for monetary policy between country-wide and sectoral productivity shocks. His model assumes a representative household, so that issues of labour mobility do not arise, and the volume of trade as well as the elasticity of substitution between goods are fixed.

The paper is organized as follows. The baseline model is described in section 1. The one-sector economy is examined in section 2, and the two-sector economy in section 3. The case of fixed costs in production is considered in section 4. The final section concludes and offers suggestions for future research.

1 The Baseline Model

We consider a one-period small open economy that trades with the rest of the world. The domestic economy consists of a primary-goods sector, which takes world prices as given, and a non-primary-goods sector, the characteristics of which will be described below. Both types of goods can be traded.⁷ Home-produced and foreign-produced primary goods are assumed to be perfect substitutes for each other, whereas non-primary goods are differentiated.

1.1 Households

The total number of households in the economy is assumed constant and normalized to equal 1. Households have identical preferences over the consumption of goods, leisure, and real money balances. The periodic utility of a household is

$$\frac{1}{1-\sigma} C^{1-\sigma} - \frac{1}{1+\phi} N^{1+\phi} + \chi \ln\left(\frac{M}{P}\right),$$

where N is the number of hours worked, $\frac{M}{P}$ are real money balances, and C is consumption of a composite of goods:

$$C = \left(\frac{C_X}{\gamma_X}\right)^{\gamma_X} \left(\frac{C_I}{\gamma_I}\right)^{1-\gamma_X},$$

6. We became aware of this study while working on our model.

7. The model can easily be extended to the case that includes non-traded goods.

$$C_T = \left[\gamma_H^{\frac{1}{\eta}} C_H^{\frac{\eta-1}{\eta}} + (1 - \gamma_H)^{\frac{1}{\eta}} C_F^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}.$$

C_X , C_H , and C_F denote, respectively, consumption of primary goods, home-produced non-primary goods (H -goods), and imported non-primary goods (F -goods). The elasticity of substitution, η , between H -goods and F -goods is assumed to be greater than or equal to 1.⁸

Households choose consumption allocations and money balances after shocks are realized, subject to the budget constraint

$$P_X C_X + P_T C_T + M = WN + \Pi + T,$$

where Π denotes dividends, and W is the wage.

Standard optimization then implies that a household's holding of money balances and expenditures on the various types of good are:

$$P_X C_X = \gamma_X P C,$$

$$P_T C_T = (1 - \gamma_X) P C,$$

$$P_H C_H = \gamma_H \left(\frac{P_H}{P_T} \right)^{1-\eta} P_T C_T,$$

$$P_F C_F = (1 - \gamma_H) \left(\frac{P_F}{P_T} \right)^{1-\eta} P_T C_T,$$

and

$$\frac{M}{P} = \chi C^\sigma,$$

where P_i is the (domestic-currency) price of goods in sector i , P is the aggregate price index, and P_T is the price index of non-primary goods.⁹

$$P = P_X^{\gamma_X} P_T^{1-\gamma_X},$$

8. The limit case $\eta = 1$ is identified with the Cobb-Douglas functional form.

9. The price index of a composite good can be defined as the minimum expenditure needed to buy one unit of the composite good.

$$P_T = [\gamma_H P_H^{1-\eta} + (1-\gamma_H) P_F^{1-\eta}]^{\frac{1}{1-\eta}}.$$

1.2 Production

Production in sector i ($i = X, H$) requires a continuum of differentiated types of labour, ij , $j \in [0, 1]$. Each household is associated with one type of labour, but several households may be associated with the same type. The number of households of each type and the number of firms in any sector are assumed constant. To examine the effect of labour mobility between sectors, we will consider the case where both sectors employ the same types of labour, i.e., type Xj and type Hj are identical. Otherwise, type Xj and type Hl are assumed to be different for all j and l .

All firms in a given sector are identical and have decreasing returns-to-scale production technologies. Specifically, output by a firm in sector i is

$$Y_i = \frac{1}{1-\alpha} A_i L_i^{1-\alpha},$$

$$L_i = \left(\int_0^1 l(ij)^{\frac{\lambda-1}{\lambda}} dj \right)^{\frac{\lambda}{\lambda-1}},$$

where $l(ij)$ is labour input of type ij , $0 \leq \alpha < 1$, $\lambda \geq 1$, and A_i is a sector-wide technological shock.

Firms take prices and wages as given and choose their volume of output after shocks are realized. Profit maximization then implies that demand by a firm in sector i for composite labour and individual labour of type ij is

$$L_i = \left[\frac{A_i P_i}{W_i} \right]^{\frac{1}{\alpha}} \text{ and } l(ij) = \left[\frac{W_i}{W(ij)} \right]^{\lambda} L_i,$$

where $W(ij)$ is the wage for labour of type ij , and W_i is a wage index for labour employed in sector i .¹⁰

10. W_i can be interpreted as the minimum cost of a unit of composite labour.

$$W_i = \left(\int_0^1 W(ij)^{1-\lambda} dj \right)^{\frac{1}{1-\lambda}}.$$

Thus, all else being equal, the higher the price markup over wages, the larger the demand is for labour and the larger output is by each firm.

1.3 Price determination

We assume throughout that the law of one price holds for all goods, i.e., $P_i = SP_i^f$, $i = X, H, F$, where S is the nominal exchange rate, expressed as the domestic price of a unit of foreign currency, and f superscript indicates foreign variables. Furthermore, on the basis that the domestic markets are small, prices of primary goods and foreign goods will be assumed to be determined in the world market and exogenously given. We will consider, however, the case where the price of home-produced non-primary goods is endogenously determined.

1.4 Wage-setting

We assume that households of the same type pool their resources and jointly set their wages. We will also consider the case where wages are pre-determined and the case where they are flexible. In the former, households are assumed to set wages at the beginning of the period, before shocks are realized, to maximize expected utility. The first-order condition then implies

$$W(ij) = \frac{\lambda}{\lambda-1} \frac{E[l^h(ij)^{1+\phi}]}{E\left[\frac{l^h(ij)}{PC(ij)^\sigma}\right]},$$

where E is the expectations operator, and $l^h(ij)$ denotes the demand for labour per household of type ij .

In the case of flexible wages, households set wages after shocks are realized to maximize their utility. The first-order condition then implies

$$W(ij) = \frac{\lambda}{\lambda-1} PC(ij)^\sigma l^h(ij)^\phi.$$

2 One-sector economy

In this section, we assume that there is only one sector in the economy, identified with the primary goods sector. Accordingly, households consume only primary goods and imported non-primary goods or, in other words, $\gamma_H = 0$. The domestic price level is then completely determined by the exchange rate and the exogenously given world prices, and relative prices and the terms of trade are exogenously given:

$$P = S(P_X^f)^\gamma (P_F^f)^{1-\gamma} \quad (\gamma \equiv \gamma_X)$$

$$\frac{P_X}{P_F} = \frac{P_X^f}{P_F^f} \quad \frac{P_X}{P} = \left(\frac{P_X^f}{P_F^f} \right)^{1-\gamma}$$

Domestic monetary policy therefore has no effect on the terms of trade in this scenario, and the ratio of primary goods consumption to imported goods consumption depends only on world prices:

$$\frac{C_X}{C_F} = \frac{\gamma}{1-\gamma} \frac{P_F}{P_X} = \frac{\gamma}{1-\gamma} \frac{P_F^f}{P_X^f}$$

2.1 Equilibrium

We focus on symmetric equilibria, whereby all households supply the same amount of labour and earn equal wages, i.e., $L = l(ij)$ and $W = w(ij)$ for all j . (The subscript X , which refers to the domestic sector, will be omitted from now on when there is no ambiguity.)

The home country sells primary goods in the world market and buys foreign goods in return. In equilibrium, prices adjust to equate total expenditures with income,

$$PC = nP_X Y,$$

where n is the number of firms in the sector. Hence, equilibrium aggregate consumption is

$$C = \frac{n}{1-\alpha} A \frac{P_X}{P} L^{1-\alpha} = \frac{n}{1-\alpha} \left(A \frac{P_X}{P} \right)^{\frac{1}{\alpha}} \left[\frac{P}{W} \right]^{\frac{1-\alpha}{\alpha}}$$

2.1.1 Flexible wages

Since there is only one sector in the domestic economy (and the total number of households equals 1), the demand for labour per household is $l^h = nL$, and therefore real wages are

$$\frac{W}{P} = \frac{\lambda}{\lambda-1} C^\sigma (nL)^\phi.$$

Substituting the expressions for equilibrium consumption and labour demand, it follows that

$$\left(\frac{W}{P}\right)^\Theta = \left[\frac{\lambda}{\lambda-1}\right]^\alpha \left(\frac{1}{1-\alpha}\right)^{\alpha\sigma} \left(\frac{n^\alpha A P_X}{P}\right)^{\phi+\sigma},$$

$$\left(\frac{W}{P_X}\right)^\Theta = \left[\frac{\lambda}{\lambda-1}\right]^\alpha \left(\frac{1}{1-\alpha}\right)^{\alpha\sigma} (n^\alpha A)^{\phi+\sigma} \left(\frac{P_X}{P}\right)^{(-\alpha)(1-\sigma)},$$

$$C^\Theta = \left[\frac{\lambda-1}{\lambda}\right]^{1-\alpha} \left(\frac{1}{1-\alpha}\right)^{\alpha+\phi} \left(\frac{n^\alpha A P_X}{P}\right)^{(1+\phi)},$$

$$L^\Theta = \left[\frac{\lambda-1}{\lambda}\right] (1-\alpha)^\sigma \frac{1}{n^{\phi+\sigma}} \left(\frac{A P_X}{P}\right)^{1-\sigma},$$

where

$$\Theta \equiv 1 + \phi - (1-\sigma)(1-\alpha) = \phi + \alpha + \sigma(1-\alpha).$$

All else being equal, a lower relative price of primary goods leads to lower income from exports, hence lower consumption, output, and demand for labour. Under flexible wages, the lower demand for labour is partly offset by lower real wages. Nevertheless, wages relative to primary goods prices increase because of the higher marginal product of labour.

2.1.2 Predetermined wages

Substituting equilibrium aggregate consumption in $M = \chi P C^\sigma$, it follows that

$$P^{\alpha+\sigma(1-\alpha)} = \chi^{-\alpha} \left(\frac{1-\alpha}{n}\right)^{\sigma\alpha} \left(A_X \frac{P_X}{P}\right)^{-\sigma} W^{\sigma(1-\alpha)} M^\alpha,$$

$$P_X^{\alpha + \sigma(1-\alpha)} = \chi^{-\alpha} \left(\frac{1-\alpha}{n} \right)^{\sigma\alpha} A_X^{-\sigma} \left(\frac{P_X}{P} \right)^{\alpha(1-\sigma)} W^{\sigma(1-\alpha)} M^{-\alpha},$$

$$S^{\alpha + \sigma(1-\alpha)} = \chi^{-\alpha} \left(\frac{1-\alpha}{n} \right)^{\sigma\alpha} A_X^{-\sigma} \left(\frac{P_X}{P} \right)^{\alpha(1-\sigma)} W^{\sigma(1-\alpha)} M^{\alpha} (P_X^f)^{-(\alpha + \sigma(1-\alpha))}.$$

From the first-order equation for predetermined wages,

$$W = \frac{1}{\chi\lambda - 1} \frac{E[(nL)^{1+\phi}]}{E\left[\frac{nL}{M}\right]},$$

it follows that

$$W^{\frac{\alpha + \phi}{\alpha}} = \frac{1}{\chi\lambda - 1} \frac{E\left[n^{1+\phi} (AP_X)^{\frac{1+\phi}{\alpha}}\right]}{E\left[\frac{n(AP_X)^{\frac{1}{\alpha}}}{M}\right]},$$

$$(\chi W)^{\frac{\Theta}{\alpha + \sigma(1-\alpha)}} = K \frac{E\left[\left(A \frac{P_X}{P}\right)^{\frac{(1+\phi)(1-\sigma)}{\alpha + \sigma(1-\alpha)}} M^{\frac{1+\phi}{\alpha + \sigma(1-\alpha)}}\right]}{E\left[\left(A \frac{P_X}{P}\right)^{\frac{(1-\sigma)}{\alpha + \sigma(1-\alpha)}} M^{\frac{(1-\alpha)(1-\sigma)}{\alpha + \sigma(1-\alpha)}}\right]},$$

where

$$K = \frac{\lambda}{\lambda - 1} (1-\alpha)^{\frac{\sigma\phi}{\alpha + \sigma(1-\alpha)}} \frac{\phi\alpha(1-\sigma)}{n^{\frac{\phi\alpha(1-\sigma)}{\alpha + \sigma(1-\alpha)}}}.$$

The above equations for P , P_X , S , and W permit one to derive various monetary policies. In particular, a fixed exchange rate policy, say $S = 1$, requires

$$M = \chi \left(\frac{1-\alpha}{n} \right)^{-\sigma} A \left(\frac{P_X}{P} \right)^{-(1-\sigma)} W^{\frac{-\sigma(1-\alpha)}{\alpha}} (P_X^f)^{\frac{\alpha + \sigma(1-\alpha)}{\alpha}}.$$

A policy that keeps the price of primary goods constant at $\bar{P}_X$ requires that the exchange rate fully offset any change in the world price of primary goods, but otherwise keeps the exchange rate constant. Such a policy obtains if

$$M = \chi \left(\frac{1-\alpha}{n} \right)^{-\sigma} A \left(\frac{P_X}{P} \right)^{-(1-\sigma)} W^{\frac{-\sigma(1-\alpha)}{\alpha}} \bar{P}_X^{\frac{\alpha + \sigma(1-\alpha)}{\alpha}}.$$

Likewise, a policy that keeps the price level constant at $\bar{P}$ requires that the exchange rate fully offset any change in the foreign price index, $P^f \equiv (P_X^f)^{\gamma} (P_F^f)^{1-\gamma}$, but otherwise keep the exchange rate constant. Such a policy obtains if

$$M = \chi \left(\frac{1-\alpha}{n} \right)^{-\sigma} \left(A_X \frac{P_X}{P} \right)^{\sigma} W^{\frac{-\sigma(1-\alpha)}{\alpha}} \bar{P}^{\frac{\alpha + \sigma(1-\alpha)}{\alpha}}.$$

None of the three policies just described is efficient in general, although they are all efficient regarding foreign shocks that do not affect the terms of trade. Indeed, in this particular case, it is best to let the exchange rate fully offset the foreign shock and insulate domestic prices and the domestic economy (see below). A similar claim, however, cannot be made with regard to shocks to the terms of trade, say a drop in the world price of primary goods. If such a shock is reflected fully in the exchange rate, and domestic prices of primary goods are kept constant, then the marginal cost of labour would be too high, since employment is kept constant. Nor should the exchange rate be kept constant and allow the shock translate in a one-for-one drop in the home-currency price of primary goods, because this would imply too low a markup over wages, and therefore lead to an inefficient loss of employment and consumption. Likewise, a policy that targets a constant price level would keep the real wage inefficiently constant.¹¹

Nevertheless, monetary policy under predetermined wages can achieve the outcome that obtains under flexible wages. To that effect, it can ensure that real wages under both regimes are equal, i.e.,

11. One can, in fact, show directly that household utility in each of these cases is lower than the utility that obtains under flexible wages.

$$\left(\frac{W}{P}\right)^{\Theta} = \left[\frac{\lambda}{\lambda-1}\right]^{\alpha} \left(\frac{1}{1-\alpha}\right)^{\alpha\sigma} \left(\frac{n^{\alpha} A_X P_X}{P}\right)^{\phi+\sigma}.$$

Hence,

$$P^{\Theta} = W^{\Theta} \left[\frac{\lambda}{\lambda-1}\right]^{-\alpha} \left(\frac{1}{1-\alpha}\right)^{-\alpha\sigma} \left(\frac{n^{\alpha} A_X P_X}{P}\right)^{-(\phi+\sigma)}$$

and

$$M^{\Theta} = [\chi W]^{\Theta} \left[\frac{\lambda-1}{\lambda}\right]^{\alpha+\sigma(1-\alpha)} \left(\frac{1}{1-\alpha}\right)^{\sigma\phi} \left[\frac{n^{\alpha} A_X P_X}{P}\right]^{-\phi(1-\sigma)}$$

$$S^{\Theta} = \left(\frac{W}{P_X^f}\right)^{\Theta} \left[\frac{\lambda}{\lambda-1}\right]^{-\alpha} \left(\frac{1}{1-\alpha}\right)^{-\alpha\sigma} (n^{\alpha} A_X)^{-(\phi+\sigma)} \left(\frac{P_X}{P}\right)^{\alpha(1-\sigma)}.$$

Written differently,

$$\hat{m} = \frac{-\phi(1-\sigma)}{\Theta} [\hat{a}_X + (1-\gamma)(\hat{p}_X - \hat{p}_F)]$$

$$\hat{s} = -\hat{p}_X^f + \frac{\alpha(1-\sigma)(1-\gamma)}{\Theta} (\hat{p}_X^f - \hat{p}_F^f) - \frac{\phi+\sigma}{\Theta} \hat{a}_X,$$

where hat superscripts denote percentage changes from the equilibrium outcome that obtains when no shocks occur. Note that

$$\frac{\alpha(1-\sigma)(1-\gamma)}{\Theta} \leq 1-\gamma \leq 1.$$

As expected, in response to a shock that does not affect the terms of trade, the money supply is kept constant, and the exchange rate adjusts to fully offset the effect on domestic prices. However, in response to decreases (respectively increases) in the relative price of primary goods, the money supply must expand (respectively contract), and the domestic currency depreciate (respectively appreciate), to offset the shock on the domestic sector. The larger the relative share, $1-\gamma$, of foreign goods in total domestic expenditures, or equivalently, the larger the share of exports in total output, the greater the effect of a change in primary goods prices on domestic income and consumption, and therefore the greater the required change in the exchange rate and money supply.

Section 2 examined monetary policy in a one-sector economy. Relative prices referred to the price of all domestic goods relative to foreign goods, and accordingly, a relative price shock is a shock across all domestic sectors. One would therefore expect monetary policy to respond fairly substantially to such shocks. In the following section, we examine how monetary responses are altered when there are two domestic sectors in the economy and the shocks affect prices in one sector relative to the other.

3 Two-Sector Economy

We now suppose that the domestic economy consists of a (non-primary) traded goods sector in addition to the primary goods sector (i.e., $\gamma_H \neq 0$). We continue to assume that prices of primary goods and prices of imported goods are determined in the world market and exogenously given. The mechanism by which prices of (non-primary) home-produced goods are determined, however, is more open to question, since the domestic market for such goods is likely to be relatively important. We therefore examine the case where it is exogenously given and the case where it is endogenously determined. We also consider alternative scenarios regarding labour mobility across sectors.¹²

All prices and wages are assumed equal in the long run,¹³ hence all firms produce the same output, and

$$\begin{aligned}\frac{\bar{C}_X}{\gamma_X} &= \frac{\bar{C}_I}{1-\gamma_X} = \frac{\bar{C}_H}{(1-\gamma_X)\gamma_H} = \frac{\bar{C}_F}{(1-\gamma_X)(1-\gamma_H)} = \bar{C} \\ &= n_X \bar{Y}_X + n_H \bar{Y}_H = (n_X + n_H) \bar{Y},\end{aligned}$$

where bar superscripts denote long-run values. The (long-run) share of exports of primary goods in total output is then

$$\alpha_X \equiv \frac{n_X \bar{Y}_X - \bar{C}_X}{(n_X + n_H) \bar{Y}} = \frac{n_X - \gamma_X(n_X + n_H)}{(n_X + n_H)};$$

the share of exports of non-primary goods in total output is

12. Not treated in this paper, but not difficult to incorporate, are alternative assumptions regarding labour mobility across national borders.

13. This is reasonable, since all firms are identical and should therefore make equal profit in the long run; and labour is mobile in the long run, hence wages cannot be systematically higher in one sector.

$$\alpha_H = \frac{n_H \bar{Y}_H - \bar{C}_H}{(n_X + n_H) \bar{Y}} = \frac{n_H - (1 - \gamma_X) \gamma_H (n_X + n_H)}{n_X + n_H};$$

the share of imports of non-primary goods must balance the share of total exports

$$\alpha_F = \alpha_X + \alpha_H = \frac{\bar{C}_F}{(n_X + n_H) \bar{Y}} = (1 - \gamma_X)(1 - \gamma_H);$$

whereas the share of the volume of trade in non-primary goods is

$$\alpha_H + \alpha_F = \alpha_X + 2\alpha_H = \frac{n_H}{n_X + n_H} + (1 - \gamma_X)(1 - \gamma_H) - (1 - \gamma_X)\gamma_H.$$

Given the changes over time in the composition of trade in Canada and the evidence of greater integration with the United States, we will be particularly interested in the implications for monetary policy of changes in the:

- relative size of the primary goods sector driven by changes in the relative number of firms;
- volume of trade in non-primary goods driven by changes in the share of consumption of home-produced non-primary goods relative to foreign-produced goods; and
- elasticity of substitution between home-produced and imported non-primary goods.

We first examine the case where prices of all goods are set in the world market and labour is perfectly mobile across domestic sectors.

3.1 Prices of all goods set in the world market, and labour perfectly mobile

All relative prices are then exogenously given, and the ratios of consumption of the various products are independent of the exchange rate and monetary policy:

$$\frac{C_X}{C_T} = \frac{\gamma_X P_T}{\gamma_T P_X},$$

$$\frac{C_H}{C_F} = \frac{\gamma_H}{1 - \gamma_H} \left(\frac{P_H}{P_F} \right)^{-\eta}.$$

The domestic sectors are assumed to employ the same types of labour. Wages are therefore equal across the domestic sectors, and relative employment and output across sectors depend only on relative prices and technological shocks and not on the exchange rate policy:

$$\frac{n_X L_X}{n_H L_H} = \frac{n_X \left[\frac{A_X P_X}{A_H P_H} \right]^{\frac{1}{\alpha}}}{n_H \left[\frac{A_H P_H}{A_H P_H} \right]^{\frac{1}{\alpha}}},$$

$$\frac{n_X Y_X}{n_H Y_H} = \frac{n_X \left[\frac{A_X}{A_H} \right]^{\frac{1}{\alpha}} \left[\frac{P_X}{P_H} \right]^{\frac{1-\alpha}{\alpha}}}{n_H \left[\frac{A_H}{A_H} \right]^{\frac{1}{\alpha}} \left[\frac{P_H}{P_H} \right]^{\frac{1-\alpha}{\alpha}}}.$$

Total demand for labour per household is

$$L = n_X L_X + n_H L_H = \Omega \left[\frac{P}{W} \right]^{\frac{1}{\alpha}},$$

where

$$\Omega = n_X \left[\frac{A_X P_X}{P} \right]^{\frac{1}{\alpha}} + n_H \left[\frac{A_H P_H}{P} \right]^{\frac{1}{\alpha}}.$$

In equilibrium, total expenditures must equal total income:

$$PC = n_X P_X Y_X + n_H P_H Y_H,$$

hence

$$C = \frac{1}{1-\alpha} \Omega \left[\frac{P}{W} \right]^{\frac{1-\alpha}{\alpha}}.$$

3.1.1 Flexible wages

$$W = \frac{\lambda}{\lambda-1} PC^{\sigma} L^{\phi},$$

hence

$$\left(\frac{W}{P} \right)^{\Theta} = \left(\frac{1}{1-\alpha} \right)^{\alpha\sigma} \left[\frac{\lambda}{\lambda-1} \right]^{\alpha} \Omega^{\alpha(\phi+\sigma)}$$

$$C^{\Theta} = \left(\frac{1}{1-\alpha} \right)^{\alpha+\phi} \left[\frac{\lambda-1}{\lambda} \right]^{1-\alpha} \Omega^{\alpha(1+\phi)}$$

$$L^{\Theta} = (1-\alpha)^{\frac{\sigma\lambda-1}{\lambda}} \Omega^{\alpha(1-\sigma)},$$

(recall $\Theta = \alpha + \phi + \sigma(1-\alpha)$).

Note that the behaviour of Ω governs the behaviour of the macro variables, and

$$\begin{aligned} \alpha \hat{\Omega} &= \alpha_X (\hat{p}_X - \hat{p}_F) + \frac{n_H}{n_X + n_H} (\hat{p}_H - \hat{p}_F) + \frac{n_X \hat{a}_X + n_H \hat{a}_H}{n_X + n_H} \\ &= \alpha_X \hat{p}_X^f + \alpha_H \hat{p}_H^f - \alpha_F \hat{p}_F^f + \frac{n_X \hat{a}_X + n_H \hat{a}_H}{n_X + n_H}. \end{aligned}$$

3.1.2 Predetermined wages

$$W = \frac{1}{\chi} \frac{\lambda}{\lambda-1} \frac{E[L^{1+\phi}]}{E\left[\frac{L}{M}\right]}.$$

As in the one-sector model, monetary policy can reproduce the outcome that obtains under flexible wages: for this purpose, it suffices to ensure that real wages under both regimes are equal. This would require

$$P^{\Theta} = W^{\Theta} \left[\frac{\lambda}{\lambda-1} \right]^{-\alpha} \left(\frac{1}{1-\alpha} \right)^{-\alpha\sigma} \Omega^{-\alpha(\phi+\sigma)},$$

hence

$$M^{\Theta} = (\chi W)^{\Theta} \left[\frac{\lambda}{\lambda-1} \right]^{-\alpha-\sigma(1-\alpha)} \left(\frac{1}{1-\alpha} \right)^{\sigma\phi} \Omega^{-\alpha\phi(1-\sigma)}.$$

Equivalently, in terms of the exchange rate,

$$\begin{aligned}
\dot{s} &= \dot{p}_X - \dot{p}_X^f = \dot{p}_X - \dot{p} + \dot{p} - \dot{p}_X^f = (1 - \gamma_X)(\dot{p}_X^f - \dot{p}_f^f) - \frac{\alpha(\phi + \sigma)}{\Theta} \dot{\Omega} - \dot{p}_X^f \\
&= -\gamma_X \dot{p}_X^f - (1 - \gamma_X) \dot{p}_f^f - \frac{(\phi + \sigma)}{\Theta} \left(\alpha_X \dot{p}_X^f + \alpha_H \dot{p}_H^f - \alpha_f \dot{p}_f^f + \frac{n_X \dot{a}_X + n_H \dot{a}_H}{n_X + n_H} \right) \\
&= -\left[\gamma_X + \frac{(\phi + \sigma)}{\Theta} \alpha_X \right] \dot{p}_X^f - \left[(1 - \gamma_X) \gamma_H + \frac{(\phi + \sigma)}{\Theta} \alpha_H \right] \dot{p}_H^f - \\
&\quad - \left[\frac{\alpha(1 - \sigma)}{\Theta} \alpha_f \right] \dot{p}_f^f - \frac{(\phi + \sigma) n_X \dot{a}_X + n_H \dot{a}_H}{\Theta (n_X + n_H)}.
\end{aligned}$$

Not surprisingly, under flexible wages, the effect of changes in relative prices on the domestic economy depends on the share of imports/exports of the goods directly affected. For instance, assuming the home country is a net exporter of primary goods, a lower relative price of primary goods entails a lower income from exports of that good, hence lower employment in the primary goods sector as labour shifts to the other sector. Decreasing returns to scale then entail lower real wages and lower aggregate employment.

Accordingly, the monetary response to a relative price shock depends on the share of imports/exports of the good affected directly by the shock. In particular, all else being equal, the volume of trade of non-primary goods has no bearing on the monetary response to changes in the relative price of primary goods.

3.2 Prices of all goods set in the world market, and no labour mobility

The domestic sectors are now assumed to employ different types of labour, so wages can be different across sectors. We nevertheless assume that consumption is the same across households, because of, for instance, non-distortionary taxes or transfers. A balanced account in equilibrium then implies

$$PC = n_X P_X Y_X + n_H P_H Y_H,$$

hence

$$C = \frac{n_X}{1 - \alpha} \left(A_X \frac{P_X}{P} \right)^{\frac{1}{\alpha}} \left[\frac{P}{W_X} \right]^{\frac{1 - \alpha}{\alpha}} + \frac{n_H}{1 - \alpha} \left(A_H \frac{P_H}{P} \right)^{\frac{1}{\alpha}} \left[\frac{P}{W_H} \right]^{\frac{1 - \alpha}{\alpha}}.$$

3.2.1 Flexible wages

$$\left(\frac{W_i}{P}\right)^{\frac{\alpha+\phi}{\alpha}} = \frac{\lambda}{\lambda-1} n^\phi C^\sigma \left[A_i \frac{P_i}{P}\right]^{\frac{\phi}{\alpha}}.$$

Substituting the expressions for sectoral wages into the expression for equilibrium consumption,

$$C^\Theta = \left(\frac{1}{1-\alpha}\right)^{\alpha+\phi} \left(n^\phi \frac{\lambda}{\lambda-1}\right)^{-(1-\alpha)} \Omega^{\alpha(1+\phi)},$$

$$\left(\frac{W_i}{P}\right)^\Theta = \left[\frac{\lambda}{\lambda-1}\right]^\alpha n^{\alpha\phi} \left(\frac{1}{1-\alpha}\right)^{\alpha\sigma} \Omega^{\alpha(1+\phi)\frac{\alpha\sigma}{\alpha+\phi}} \left[A_i \frac{P_i}{P}\right]^{\frac{\phi\Theta}{\alpha+\phi}},$$

$$L_i^\Theta = \frac{\lambda-1}{\lambda} n^{-\phi} (1-\alpha)^\sigma \Omega^{-(1+\phi)\frac{\alpha\sigma}{\alpha+\phi}} \left[A_i \frac{P_i}{P}\right]^{\frac{\Theta}{\alpha+\phi}},$$

where

$$\Omega^{\alpha(1+\phi)} = \left[n_X \left(A_X \frac{P_X}{P}\right)^{\frac{1+\phi}{\alpha+\phi}} + n_H \left(A_H \frac{P_H}{P}\right)^{\frac{1+\phi}{\alpha+\phi}} \right]^{\alpha+\phi}.$$

Note that the variable Ω is different from that in the previous section, but to a first-order approximation, it has the same percentage deviations from initial conditions,

$$\alpha \hat{\Omega} = \alpha_X \hat{p}_X^f + \alpha_H \hat{p}_H^f - \alpha_f \hat{p}_f^f + \frac{n_X \hat{a}_X + n_H \hat{a}_H}{n_X + n_H}.$$

Consequently, the outcome at the sectoral level is different from the result that obtains when labour is mobile. Following a negative shock to primary goods prices, real wages for households in that sector fall more, and employment falls less than it would if labour were mobile, assuming the home country is a net exporter of primary goods. By the same token, real wages rise more and employment rises less in the other sector, because unemployment in the primary goods sector does not translate directly into an increased supply of labour in the other sector. Rather, the lower income from exports of primary goods, and increased transfers due to higher unemployment, translate into lower wages, hence higher employment and

output in the non-primary goods sector. Nonetheless, at the aggregate level, and to a first-order approximation, deviations in real wages,¹⁴ employment, consumption, and output are the same in both scenarios (see details in Appendix). Also, the volume of trade in the non-primary goods sector still has no bearing on the effects that such shocks have on the economy.

3.2.2 Predetermined wages

Note that under flexible wages, the ratio of wages across the two sectors depends on relative prices,

$$\frac{W_X}{W_H} = \left[\frac{A_X P_X}{A_H P_H} \right]^{\frac{\phi}{\alpha + \phi}},$$

whereas, under predetermined wages, the ratio is, of course, constant. Thus, in general, monetary policy cannot reproduce the outcome that obtains under flexible wages and no labour mobility at the sectoral level. It can, however, reproduce the outcome at the aggregate level. To that effect it suffices to ensure that aggregate real wages equal those that prevail under flexible wages.¹⁵ Under these conditions, output, in the aggregate as well as in each sector, and hence consumption and aggregate employment, would be the same as in the flexible case with labour mobility. But naturally, employment per household of each type will be different, since households in one sector would be called on to work more or less to offset the fluctuations in employment caused by inflexible wages in the other sector.

3.3 Prices of home-produced non-primary goods endogenous, labour fully mobile

In this scenario, prices of primary goods and foreign-produced non-primary goods are still determined in the world market; however, prices of home-produced non-primary goods adjust to make supply and demand equal.¹⁶ Specifically, the demand for exports of non-primary goods is assumed to satisfy

14. The aggregate wage index is

$$\frac{W}{P} = \left(\frac{W_X}{P} \right)^{\frac{\alpha_X}{\alpha_X + \alpha_H}} \left(\frac{W_H}{P} \right)^{\frac{\alpha_H}{\alpha_X + \alpha_H}}.$$

15. With or without labour mobility.

16. An alternative scenario with similar consequences is that prices of imported goods depend on domestic demand, i.e., there is pricing to market by foreign firms.

$$EX_H = \theta \left(\frac{P_H}{P_T} \right)^{-\eta},$$

where θ is the volume of exports of H -goods that obtain in the long-run, i.e.,

$$\theta = \alpha_H \left(\frac{1}{1-\alpha} \right)^{\frac{\alpha+\phi}{\Theta}} \left[\frac{\lambda-1}{\lambda} \right]^{\frac{1-\alpha}{\Theta}} (n_X + n_H)^{\frac{\alpha(1+\phi)}{\Theta}}.$$

The same derivations as in section 3.1 imply

$$L = \Omega \left[\frac{P}{W} \right]^{\frac{1}{\alpha}},$$

$$C = \frac{1}{1-\alpha} \Omega \left[\frac{P}{W} \right]^{\frac{1-\alpha}{\alpha}},$$

with Ω defined as in section 3.1.

Now, however, relative prices, and hence Ω , are not exogenously given. Rather, the price of H -goods adjusts so that total demand for home-produced traded goods equals supply, i.e.,

$$C_H + EX_H = n_H Y_H,$$

hence

$$(1-\gamma_X)\gamma_H \frac{P}{P_T} C + \theta = \frac{1}{1-\alpha} n_H A_H^{\frac{1}{\alpha}} \left(\frac{P_H}{P_T} \right)^{\eta} \left[\frac{P_H}{W} \right]^{\frac{1-\alpha}{\alpha}}.$$

All else being equal, an increase in P_H raises output of home-produced non-primary goods, which can be liquidated only if their price relative to foreign non-primary goods falls so that domestic consumption and exports of H -goods increase.

3.3.1 Flexible wages

The same derivations as in section 3.1 give

$$\left(\frac{W}{P} \right)^{\Theta} = \left(\frac{1}{1-\alpha} \right)^{\alpha\sigma} \left[\frac{\lambda}{\lambda-1} \right]^{\alpha} \Omega^{\alpha(\phi+\sigma)}$$

$$C^{\Theta} = \left(\frac{1}{1-\alpha}\right)^{\alpha+\Phi} \left[\frac{\lambda-1}{\lambda}\right]^{1-\alpha} \Omega^{\alpha(1+\Phi)}$$

$$L^{\Theta} = (1-\alpha) \frac{\sigma\lambda-1}{\lambda} \Omega^{\alpha(1-\sigma)}.$$

Substituting into the market equilibrium condition for H -goods, it follows (see Appendix for details) that

$$\Psi(\hat{p}_X - \hat{p}_F) = \left(\frac{(1+\Phi)\alpha_H(n_X+n_H)}{\Theta}\right) \left(\frac{n_X\hat{a}_X + n_H\hat{a}_H}{n_X+n_H}\right) + \frac{1}{\alpha}\hat{a}_H + \Gamma(\hat{p}_H - \hat{p}_F),$$

and hence

$$\alpha\hat{\Omega} = \left(\alpha_X + \alpha_H \frac{\Psi}{\Gamma}\right)(\hat{p}_X - \hat{p}_F) + \left[1 - \frac{\alpha_H(1+\Phi)\alpha_H(n_X+n_H)}{\Gamma\Theta}\right] \left(\frac{n_X\hat{a}_X + n_H\hat{a}_H}{n_X+n_H}\right) - \frac{\alpha_H}{\Gamma} \frac{1}{\alpha} \hat{a}_H,$$

$$\begin{aligned} \hat{w} - \hat{p}_X &= \left[\frac{\Phi+\sigma}{\Theta}\alpha_X - (1-\gamma_X) + \left[\frac{\Phi+\sigma}{\Theta}\frac{n_H}{n_X+n_H} + \left(\frac{\alpha(1-\sigma)}{\Theta}\right)(1-\gamma_X)\gamma_H\right]\frac{\Psi}{\Gamma}\right](\hat{p}_X - \hat{p}_F) + \\ &+ \left[\frac{\Phi+\sigma}{\Theta} - \left(\frac{\Phi+\sigma}{\Theta}\frac{n_H}{n_X+n_H} + \left(\frac{\alpha(1-\sigma)}{\Theta}\right)(1-\gamma_X)\gamma_H\right)\frac{(1+\Phi)\alpha_H(n_X+n_H)}{\Gamma\Theta}\right] \left(\frac{n_X\hat{a}_X + n_H\hat{a}_H}{n_X+n_H}\right) \\ &- \left(\frac{\Phi+\sigma}{\Theta}\frac{n_H}{n_X+n_H} + \left(\frac{\alpha(1-\sigma)}{\Theta}\right)(1-\gamma_X)\gamma_H\right)\frac{1}{\Gamma\alpha}\hat{a}_H, \end{aligned}$$

where the coefficients Ψ and Γ are positive if the home country is a net exporter of primary goods.

Thus, as expected, a drop in the world price of primary goods causes a drop in the price of H -goods relative to foreign goods. Numerical approximations show that the larger the volume of foreign trade (induced by a smaller share, γ_H , of consumption of home-produced non-primary goods in total consumption of non-primary goods), the smaller the coefficients $\frac{\Psi}{\Gamma}$ and $\alpha_X + \alpha_H \frac{\Psi}{\Gamma}$ (in $\alpha\hat{\Omega}$). And therefore, the smaller the drop in the price of home-produced non-primary goods relative to imported goods following a negative shock to the price of primary goods, the larger the drop in the price of primary goods relative to wages, and the smaller the drop in aggregate real wages, employment, and consumption. A higher elasticity of substitution, η , between home-produced and foreign-produced non-primary goods, has the same effects as a larger volume of trade, but for different reasons. A higher elasticity of substitution implies that a smaller reduction

in prices is needed to clear the market for non-primary goods, whereas a larger volume of trade implies that a drop in prices is more costly in terms of income, and therefore induces greater labour supply.

3.3.2 *Predetermined wages*

As in section 3.1, since labour is assumed mobile between sectors, monetary policy can reproduce the equilibrium outcome under flexible wages. Again, it suffices to ensure that real wages equal those that obtain when wages are flexible. The results above showed that when wages are flexible, the larger the volume of foreign trade and the larger the elasticity of substitution between home-produced non-primary goods and imported goods, the larger the drop in the price of primary goods relative to wages following a negative shock to the price of primary goods, and therefore the exchange rate should offset the shock to a lesser degree.

In all the cases considered so far, there is no sense in which monetary policy promotes low productivity in the primary goods sector following a negative shock. When labour was assumed to be perfectly mobile, it was found that monetary policy can, in fact, reproduce the flexible-wage outcome, and when labour was not mobile, it was found that, if anything, monetary policy would sustain higher marginal productivity of labour in the primary goods sector than in the flexible-wage case. The next section describes a model whereby monetary policy can sometimes sustain inefficient productivity.

4 One-Sector Economy with Fixed Costs in Production

In this section, we make the same assumptions as in the one-sector model described in section 2, except that now firms can incur a fixed cost of production along the same lines as in Blanchard and Kiyotaki (1987).¹⁷ Specifically, output by a firm in the domestic sector is now given by

$$Y = \frac{1}{1-\alpha} AL^{1-\alpha} - c,$$

where c is a fixed cost (expressed in the firm's own good) that is allowed to be different from one firm to another. Aside from the obvious interpretation, differences in fixed costs between firms can also be thought of as differences in efficiency of production.¹⁸

17. One difference in our model, with important implications, is that the total number of firms in the sector that can potentially produce output is fixed and firms have decreasing returns-to-scale technology.

18. In a partial-equilibrium setting, the fixed cost can also be thought of as an opportunity cost for doing business in a particular sector.

The presence of fixed costs means that some firms may choose not to produce following a negative shock. More formally, profits by a firm with fixed costs c are

$$\Pi = P_X Y - WL = \frac{\alpha}{1-\alpha} A_X \left(\frac{P_X}{W} \right)^{\frac{1}{\alpha}} W - P_X c.$$

It follows that such a firm admits non-negative profits, and therefore produces output if

$$\frac{P_X}{W} \geq \left(\frac{1-\alpha}{\alpha} c \right)^{\frac{\alpha}{1-\alpha}} A_X^{\frac{1}{1-\alpha}},$$

i.e., if the price markup over wages is above a certain threshold or, equivalently, if

$$c \leq \frac{\alpha}{1-\alpha} A_X \left(\frac{P_X}{W} \right)^{\frac{1}{\alpha}},$$

i.e., if the fixed cost is below a certain threshold.

The total domestic output following a shock is

$$totY = \frac{n}{1-\alpha} A_X L^{1-\alpha} - totc,$$

where n is now the number of firms that do produce output,¹⁹ which may be smaller than the total number $\bar{n}$ of firms in the sector, and $totc$ is the total fixed cost of production incurred in the sector (e.g., $totc = nc$ if firms have identical fixed costs). Accordingly, market equilibrium is now written as

$$PC = P_X totY,$$

and the equilibrium level of aggregate consumption is

$$C = \frac{n}{1-\alpha} A_X \frac{P_X}{P} L^{1-\alpha} - \frac{P_X}{P} totc = \frac{n}{1-\alpha} \left(A_X \frac{P_X}{P} \right)^{\frac{1}{\alpha}} \left[\frac{P}{W} \right]^{\frac{1-\alpha}{\alpha}} - \frac{P_X}{P} totc.$$

19. To simplify the derivations, this number is allowed to be a fraction.

4.1 Flexible wages

Households are assumed to take the number, n , of firms in operation as given when they set their wages.²⁰ The first-order equation for wages is

$$W = \frac{\lambda}{\lambda - 1} PC^\sigma (nL)^\phi.$$

Substituting equilibrium consumption gives

$$W = \frac{\lambda}{\lambda - 1} P \left(\frac{n}{1 - \alpha} A_X \frac{P_X}{P} L^{1 - \alpha} - \frac{P_X}{P} \text{totc} \right)^\sigma (nL)^\phi.$$

On the other hand,

$$L = \left(\frac{AP_X}{P} \right)^{\frac{1}{\alpha}} \left[\frac{P}{W} \right]^{\frac{1}{\alpha}}.$$

It follows that the markup satisfies

$$\left[\frac{P_X}{W} \right]^{\frac{\alpha + \phi}{\alpha \sigma}} n^{\frac{\phi}{\sigma}} \left(\frac{n}{1 - \alpha} A \left[\frac{P_X}{W} \right]^{\frac{1 - \alpha}{\alpha}} - \text{totc} \right) = \left(\frac{\lambda}{\lambda - 1} \right)^{\frac{1}{\sigma}} A^{-\frac{\phi}{\alpha \sigma}} \left(\frac{P_X}{P} \right)^{\frac{(1 - \sigma)}{\sigma}}.$$

The larger the number, n , of firms in operation, the higher the demand for labour, the higher the real wage and the smaller the markup (see proof in Appendix). If the threshold for positive profits is binding for some value $\bar{c}$ of the fixed cost, then

$$n^{\phi} \left(\frac{n\bar{c}}{\alpha} - \text{totc} \right)^{\sigma} = \left(\frac{\lambda - 1}{\lambda} \right) \left(\frac{1 - \alpha}{\alpha} \bar{c} \right)^{\frac{-(\alpha + \phi)}{1 - \alpha}} A^{\frac{(1 + \phi)}{1 - \alpha}} \left(\frac{P_X}{P} \right)^{(1 - \sigma)}.$$

(In particular, if all firms admit the same fixed costs, then

$$n^{\phi + \sigma} = \left(\frac{\lambda - 1}{\lambda} \right) \left(\frac{1 - \alpha}{\alpha} \bar{c} \right)^{\frac{-(\alpha + \phi) + \sigma(1 - \alpha)}{1 - \alpha}} A_X^{\frac{(1 + \phi)}{1 - \alpha}} \left(\frac{P_X}{P} \right)^{(1 - \sigma)}.)$$

20. It would be interesting to examine the case where households take into consideration the effect of their wage demands on the subsistence of the firm.

If the total number of firms in the sector, $\bar{n}$, is smaller than the number n that satisfies the equation above with the highest possible value of the fixed cost chosen for $\bar{c}$, then all the firms in the sector produce output. Otherwise, there is an upper limit $\bar{c}$ on c , such that only firms with fixed costs less than or equal to $\bar{c}$ can make non-negative profits, and the number of such firms cannot exceed the number n that satisfies the equation above. A favourable change in the terms of trade increases the number of firms in operation. But as long as this number is no greater than the total number of firms in the sector with fixed costs less than or equal to $\bar{c}$, the markup and employment per firm remain constant at

$$\frac{P_X}{W} = \left(\frac{1-\alpha}{\alpha} c \right)^{\frac{\alpha}{1-\alpha}} A_X^{-\frac{1}{1-\alpha}} \text{ and } L = \left(\frac{A_X P_X}{W} \right)^{\frac{1}{\alpha}}.$$

More generally, if the firms' fixed costs do not differ too much, then the markup ought to change relatively little with changes in the terms of trade. Aggregate production would have close to constant returns to scale as long as some firms remain idle, and changes in the terms of trade would be passed on to wages. However, once the economy reaches capacity, in the sense that all the firms are in operation, then higher aggregate production can obtain only by means of increases in the production of individual firms, in which case, domestic goods prices would increase faster than wages because of decreasing returns to scale.²¹ The Appendix illustrates the case where firms' fixed costs are distributed uniformly on the interval $[0,1]$.

4.1.1 Predetermined wages

One can think of two reasons why, in the flexible-wage case, a firm may not produce output following a negative shock to the terms-of-trade prices. Either its fixed costs are too high to operate at the level to which wages adjust in equilibrium, or the level of wages at which it can attract (or retain) labour is too high. If firms are sufficiently differentiated by their fixed costs so that those firms that choose not to produce do so strictly because of their higher fixed costs, then, as in the case without fixed costs, monetary policy can reproduce the flexible-wage outcome by causing the local currency to depreciate and domestic prices to rise until real wages equal those that obtain under flexible wages.

Nonetheless, monetary policy ought to be different depending on whether or not the economy has reached full capacity. Since, under flexible wages, the elasticity of the markup to changes in the terms of trade is lower when the

21. To see this, differentiate the expression for wages in terms of $\frac{P_X}{P}$.

economy is below full capacity, the exchange rate must depreciate more in response to the negative shock in that case.²² The Appendix illustrates the case where the fixed costs of firms are distributed uniformly on the interval $[0,1]$.

If firms are not sufficiently differentiated by their fixed costs to begin with, then fixing the real wage to that which prevails under flexible wages would sustain production in inefficient firms, i.e., in firms that would not have produced if wages could adjust. Under such conditions, therefore, monetary policy cannot reproduce the flexible-wage outcome. What then, is an efficient policy?

If, in fact, all firms have equal fixed costs, then following a shock, either all firms produce output or none does. However, the latter outcome clearly cannot be efficient since it entails no income and hence no consumption by households. In this case, monetary policy always sustains production by all firms, even if some firms are inefficient.²³

This result depends, however, on all firms having equal fixed costs. The presence of firms with different fixed costs makes it possible that for some range of the terms of trade it is optimum, as in the previous case, to offset shocks to the terms of trade and keep the price of primary goods at a level that sustains inefficient production. For another range of relative prices, however, it is optimum to allow the price of primary goods to fall to a level that thwarts production in certain firms in spite of the fact that they would be efficient if wages could adjust.²⁴

22. By the same token, this also implies that prices must be allowed to change more when the economy is at full capacity. Of course this does not take into consideration the risks of inflation. One must introduce dynamics in the model to tackle such questions.

23. Heuristically, the policy that seems closest to reproducing the flexible-wage outcome is the policy that keeps the price of primary goods (hence the markup) constant as long as the terms of trade are below the threshold that entails positive profits in the flexible-wage case, i.e., as long as the potential number,

$$n^{\varphi+\sigma} = \left(\frac{\lambda-1}{\lambda} \right) \left(\frac{1-\alpha}{\alpha} c \right)^{\frac{-(\alpha+\varphi)+\sigma(1-\alpha)}{1-\alpha}} A_X^{\frac{(1+\varphi)}{1-\alpha}} \left(\frac{P_X}{P} \right)^{(1-\sigma)},$$

of firms that can be sustained is no greater than the total number of firms in the sector. Over that range of values for the terms of trade, employment is therefore higher than it would be under flexible wages. Conversely, for the equilibrium to exist, employment likely has to be lower than it would be under flexible wages for values above the threshold. A more formal proof of this claim is outside the scope of this paper.

24. Alternatively, one can obtain similar outcomes even if all firms are identical, if one incorporates a second sector in the economy that can provide a substitute income.

Conclusions

This paper applies the New Keynesian open-economy modelling approach to examine monetary policy in the context of the Canadian economy. For that purpose, it develops a simple one-period model of a small open economy with nominal-wage rigidities, price-taking firms, and decreasing returns-to-scale technology.

The paper first looks at a one-sector case and shows that the efficient monetary policy conforms to conventional wisdom. Specifically, following a negative shock to the relative price of domestic goods, the local currency must depreciate to counteract the rigidity of wages. Next, it examines a two-sector model, with one sector standing for primary goods, the prices of which are set in the world market, and another sector standing for traded non-primary (e.g., manufactured) goods. It is subsequently shown that, as in the one-sector model, the domestic currency needs to depreciate following a negative shock to the relative price of primary goods, but that typically, higher economic integration, represented by a higher volume of international trade or higher elasticity of substitution between domestic and foreign (non-primary) goods, would induce smaller currency depreciations. Finally, the paper considers a one-sector model with fixed costs in production, and shows that monetary policy cannot always reproduce the flexible-wage outcome in such an environment. In fact, in some circumstances, monetary policy may stifle productivity, in the sense that it may have to sustain production in firms that would make negative profits in a perfectly flexible environment.

The model can be easily extended to examine a number of other questions, for instance, the effect of labour mobility across countries on the conduct of monetary policy, or the effects of adjustment costs in labour markets. While it allows one to abstract from dynamics, the restriction of the model to a single period strongly limits the breadth of the results. Extension to an infinite horizon is the natural next step in this research.

Appendix

Two-Sector Economy

All prices set in the world market, labour not mobile

Claim: Under flexible wages, real wages in the primary goods sector following a shock to prices in that sector deviate less, and employment deviates more when labour is mobile than when it is not, assuming that the home country is a net exporter of primary goods. However, to a first-order approximation, aggregate real wages and employment deviate equally in both scenarios.

Indeed, real wages (in either sector) when labour is mobile are

$$\left(\frac{W}{P}\right)^{\Theta} = \left(\frac{1}{1-\alpha}\right)^{\alpha\sigma} \left[\frac{\lambda}{\lambda-1}\right]^{\alpha} \Omega^{\alpha(\phi+\sigma)},$$

and hence, in percentage deviations from initial conditions,

$$\Theta(\hat{w} - \hat{p}) = \alpha(\phi + \sigma)\hat{\Omega} = (\phi + \sigma)\left(\alpha_X\hat{p}_X^f + \alpha_H\hat{p}_H^f - \alpha_F\hat{p}_F^f + \frac{n_X\hat{a}_X + n_H\hat{a}_H}{n_X + n_H}\right);$$

whereas, when labour is not mobile,

$$\left(\frac{W_i}{P}\right)^{\Theta} = \left[\frac{\lambda}{\lambda-1}\right]^{\alpha} n^{\alpha\phi} \left(\frac{1}{1-\alpha}\right)^{\alpha\sigma} \Omega^{\alpha(1+\phi)} \left[A_i \frac{P_i}{P}\right]^{\frac{\phi\Theta}{\alpha+\phi}},$$

hence

$$\begin{aligned} \Theta(\hat{w}_i - \hat{p}) &= \alpha(1+\phi) \frac{\alpha\sigma}{\alpha+\phi} \hat{\Omega} + \frac{\phi\Theta}{\alpha+\phi} (\hat{a}_i + \hat{p}_i - \hat{p}) \\ &= (1+\phi) \frac{\alpha\sigma}{\alpha+\phi} \left(\alpha_X\hat{p}_X^f + \alpha_H\hat{p}_H^f - \alpha_F\hat{p}_F^f + \frac{n_X\hat{a}_X + n_H\hat{a}_H}{n_X + n_H}\right) + \frac{\phi\Theta}{\alpha+\phi} (\hat{a}_i + \hat{p}_i - \hat{p}). \end{aligned}$$

Recall that, in either case,

$$\begin{aligned} \alpha\hat{\Omega} &= \alpha_X(\hat{p}_X - \hat{p}_T) + \frac{n_H}{n_X + n_H}(\hat{p}_H - \hat{p}_T) + \frac{n_X\hat{a}_X + n_H\hat{a}_H}{n_X + n_H} \\ &= \alpha_X\hat{p}_X^f + \alpha_H\hat{p}_H^f - \alpha_F\hat{p}_F^f + \frac{n_X\hat{a}_X + n_H\hat{a}_H}{n_X + n_H} \end{aligned}$$

Thus, the elasticity of real wages with respect to $\hat{p}_X^f$ is

$(\phi + \sigma)\alpha_X$ when labour is mobile, and

$$(1 + \varphi) \frac{\alpha\sigma}{\alpha + \phi} \alpha_X + \frac{\phi\Theta}{\alpha + \phi} (1 - \gamma_X)$$

when labour is not mobile, and their difference is negative:

$$\begin{aligned} & \frac{1}{\alpha + \phi} \{ [(\phi + \sigma)(\alpha + \phi) - (1 + \varphi)\alpha\sigma] \alpha_X - \phi\Theta(1 - \gamma_X) \} \\ &= \frac{1}{\alpha + \phi} \{ \phi(\alpha + \phi + \sigma(1 - \alpha)) \alpha_X - \phi\Theta(1 - \gamma_X) \} \\ &= \frac{\phi\Theta}{\alpha + \phi} \{ \alpha_X - (1 - \gamma_X) \} = -\frac{\phi\Theta}{\alpha + \phi} \frac{n_H}{n_X + n_H}. \end{aligned}$$

The claim for sectoral employment follows immediately, since

$$L_i = \left[\frac{A_i P_i}{P} \right]^{\frac{1}{\alpha}} \left[\frac{A_i P_i}{W_i} \right]^{\frac{1}{\alpha}}$$

under either scenario.

The deviation in aggregate real wages when labour is not mobile is

$$\begin{aligned} \Theta(\hat{w} - \hat{p}) &= \Theta \left[\frac{n_X}{n_X + n_H} (\hat{w}_X - \hat{p}) + \frac{n_H}{n_X + n_H} (\hat{w}_H - \hat{p}) \right] \\ &= (1 + \varphi) \frac{\alpha\sigma}{\alpha + \phi} \alpha \hat{\Omega} + \frac{n_X}{n_X + n_H} \frac{\phi\Theta}{\alpha + \phi} (\hat{a}_X + \hat{p}_X - \hat{p}) + \frac{n_H}{n_X + n_H} \frac{\phi\Theta}{\alpha + \phi} (\hat{a}_H + \hat{p}_H - \hat{p}) \\ &= (1 + \varphi) \frac{\alpha\sigma}{\alpha + \phi} \alpha \hat{\Omega} + \frac{\phi\Theta}{\alpha + \phi} \alpha \hat{\Omega} = (\phi + \sigma) \alpha \hat{\Omega}, \end{aligned}$$

which is identical to that when labour is mobile; similarly for aggregate labour.

Prices of home-produced non-primary goods endogenous

The same derivations as above give

$$\begin{aligned} \left(\frac{W}{P} \right)^\Theta &= \left(\frac{1}{1 - \alpha} \right)^{\alpha\sigma} \left[\frac{\lambda}{\lambda - 1} \right]^\alpha \Omega^{\alpha(\phi + \sigma)} \\ C^\Theta &= \left(\frac{1}{1 - \alpha} \right)^{\alpha + \varphi} \left[\frac{\lambda - 1}{\lambda} \right]^{1 - \alpha} \Omega^{\alpha(1 + \varphi)} \end{aligned}$$

$$L^\Theta = (1 - \alpha) \frac{\sigma \lambda - 1}{\lambda} \Omega^{\alpha(1 - \sigma)}.$$

Equilibrium in the market for H -goods requires

$$(1 - \gamma_X) \gamma_H \frac{P}{P_T} C + \theta = \frac{1}{1 - \alpha} n_H A_H^{\frac{1}{\alpha}} \left(\frac{P_H}{P_T} \right)^\eta \left[\frac{P_H}{W} \right]^{\frac{1 - \alpha}{\alpha}}.$$

It follows

$$\begin{aligned} (1 - \gamma_X) \gamma_H \frac{P}{P_T} \left[\left(\frac{1}{1 - \alpha} \right)^{\frac{\alpha + \varphi}{\Theta}} \left[\frac{\lambda - 1}{\lambda} \right]^{\frac{1 - \alpha}{\Theta}} \Omega^{\frac{\alpha(1 + \varphi)}{\Theta}} \right] + \theta \\ = n_H A_H^{\frac{1}{\alpha}} \left[\frac{P_H}{P_T} \right]^{\frac{1 - \alpha + \alpha \eta}{\alpha}} \left[\frac{P_T}{P} \right]^{\frac{1 - \alpha}{\alpha}} \left(\frac{1}{1 - \alpha} \right)^{\frac{\alpha + \varphi}{\Theta}} \left[\frac{\lambda}{\lambda - 1} \right]^{\frac{(1 - \alpha)}{\Theta}} \Omega^{\frac{\alpha(1 + \varphi)}{\Theta} - 1} \end{aligned}$$

Taking log deviations from initial conditions,

$$\begin{aligned} \left[\frac{1}{\alpha} - \frac{\alpha_H(n_X + n_H)}{n_H} \right] [\gamma_X(\hat{p}_X - \hat{p}_T)] = \frac{1}{\alpha} \hat{a}_H + \frac{1 - \alpha + \alpha \eta}{\alpha} (\hat{p}_H - \hat{p}_T) \\ + \left(-\frac{1}{\alpha} + \frac{(1 + \varphi) \alpha_H(n_X + n_H)}{\Theta n_H} \right) \alpha \hat{\Omega}, \end{aligned}$$

hence

$$\begin{aligned} \left[\frac{1}{\alpha} (\gamma_X + \alpha_X) - \frac{\alpha_H(n_X + n_H)}{n_H} \left(\gamma_X + \frac{(1 + \varphi)}{\Theta} \alpha_X \right) \right] (\hat{p}_X - \hat{p}_T) = \\ + \left(\frac{1}{\alpha} \frac{n_X}{n_X + n_H} + \frac{(1 + \varphi)}{\Theta} \alpha_H + \eta - 1 \right) (\hat{p}_H - \hat{p}_T), \\ + \left(-\frac{1}{\alpha} + \frac{(1 + \varphi) \alpha_H(n_X + n_H)}{\Theta n_H} \right) \frac{n_X \hat{a}_X + n_H \hat{a}_H}{n_X + n_H} + \frac{1}{\alpha} \hat{a}_H \\ \Psi(\hat{p}_X - \hat{p}_T) = \left(\frac{(1 + \varphi) \alpha_H(n_X + n_H)}{\Theta n_H} \right) \left(\frac{n_X \hat{a}_X + n_H \hat{a}_H}{n_X + n_H} \right) + \frac{1}{\alpha} \hat{a}_H + \Gamma_1(\hat{p}_H - \hat{p}_T), \end{aligned}$$

or equivalently

$$\Psi(\dot{p}_X - \dot{p}_F) = \left(\frac{(1+\varphi)\alpha_H(n_X + n_H)}{n_H} \right) \left(\frac{n_X \dot{\alpha}_X + n_H \dot{\alpha}_H}{n_X + n_H} \right) + \frac{1}{\alpha} \dot{\alpha}_H + \Gamma(\dot{p}_H - \dot{p}_F),$$

where

$$\Gamma_1 = \frac{1}{\alpha} \frac{n_X}{n_X + n_H} + \frac{(1+\varphi)}{\Theta} \alpha_H + \eta - 1,$$

$$\Gamma = \Gamma_1(1 - \gamma_H) + \Psi\gamma_H \text{ and}$$

$$\Psi = \left[\frac{1}{\alpha} \frac{n_X}{n_X + n_H} - \left(1 - \frac{(1 - \gamma_X)\gamma_H(n_X + n_H)}{n_H} \right) \left(\frac{(1+\varphi)}{\Theta} \frac{n_X}{n_X + n_H} - \frac{(1-\alpha)(1-\sigma)}{\Theta} \gamma_X \right) \right].$$

In particular, if $\alpha_H = 0$, then

$$\Psi = \frac{1}{\alpha} \frac{n_X}{n_X + n_H} \quad \Gamma_1 = \frac{1}{\alpha} \frac{n_X}{n_X + n_H} + \eta - 1$$

$$\Gamma = \frac{1}{\alpha} \frac{n_X}{n_X + n_H} + (\eta - 1)(1 - \gamma_H)$$

$$\alpha_X + \alpha_H \frac{\Psi}{\Gamma} = \alpha_X,$$

while if $\gamma_H = 0$, then

$$\Psi = \frac{(\varphi + \sigma)(1 - \alpha)}{\alpha\Theta} \frac{n_X}{n_X + n_H} + \frac{(1 - \alpha)(1 - \sigma)}{\Theta} \gamma_X,$$

$$\Gamma_1 = \frac{1}{\alpha} \frac{n_X}{n_X + n_H} + \frac{(1+\varphi)}{\Theta} \frac{n_H}{n_X + n_H} + \eta - 1 \quad \Gamma = \Gamma_1, \text{ and}$$

$$\alpha_X + \alpha_H \frac{\Psi}{\Gamma} = \alpha_X + \frac{n_H}{n_X + n_H} \left[\frac{(\varphi + \sigma)(1 - \alpha)}{\alpha\Theta} \frac{n_X}{n_X + n_H} + \frac{(1 - \alpha)(1 - \sigma)}{\Theta} \gamma_X \right] \frac{1}{\frac{1}{\alpha} \frac{n_X}{n_X + n_H} + \frac{(1+\varphi)}{\Theta} \frac{n_H}{n_X + n_H} + \eta - 1}.$$

It follows

$$\begin{aligned} \alpha\dot{\Omega} &= \alpha_X(\dot{p}_X - \dot{p}_F) + \alpha_H(\dot{p}_H - \dot{p}_F) + \frac{n_X \dot{\alpha}_X + n_H \dot{\alpha}_H}{n_X + n_H} \\ &= \left(\alpha_X + \alpha_H \frac{\Psi}{\Gamma} \right) (\dot{p}_X - \dot{p}_F) + \left[1 - \frac{\alpha_H(1+\varphi)\alpha_H(n_X + n_H)}{\Gamma\Theta} \right] \left(\frac{n_X \dot{\alpha}_X + n_H \dot{\alpha}_H}{n_X + n_H} \right) - \frac{\alpha_H}{\Gamma} \frac{1}{\alpha} \dot{\alpha}_H \end{aligned}$$

and

$$\begin{aligned}
 \hat{w} - \hat{p}_X &= \hat{w} - \hat{p} - (1 - \gamma_X)[\hat{p}_X - \hat{p}_F - \gamma_H(\hat{p}_H - \hat{p}_F)] \\
 &= \left[\frac{\phi + \sigma}{\Theta} \alpha_X + \left[\frac{\phi + \sigma}{\Theta} \alpha_H + (1 - \gamma_X)\gamma_H \right] \frac{\Psi}{\Gamma} - (1 - \gamma_X) \right] (\hat{p}_X - \hat{p}_F) + \\
 &+ \left[\frac{\phi + \sigma}{\Theta} - \left(\frac{\phi + \sigma}{\Theta} \alpha_H + (1 - \gamma_X)\gamma_H \right) \frac{(1 + \phi)\alpha_H(n_X + n_H)}{\Gamma\Theta} \right] \left(\frac{n_X \hat{a}_X + n_H \hat{a}_H}{n_X + n_H} \right) \\
 &- \left(\frac{\phi + \sigma}{\Theta} \alpha_H + (1 - \gamma_X)\gamma_H \right) \frac{1}{\Gamma} \hat{a}_H \\
 &= \left[\frac{\phi + \sigma}{\Theta} \alpha_X - (1 - \gamma_X) + \left[\frac{\phi + \sigma}{\Theta} \frac{n_H}{n_X + n_H} + \left(\frac{\alpha(1 - \sigma)}{\Theta} \right) (1 - \gamma_X)\gamma_H \right] \frac{\Psi}{\Gamma} \right] (\hat{p}_X - \hat{p}_F) \\
 &+ \left[\frac{\phi + \sigma}{\Theta} - \left(\frac{\phi + \sigma}{\Theta} \frac{n_H}{n_X + n_H} + \left(\frac{\alpha(1 - \sigma)}{\Theta} \right) (1 - \gamma_X)\gamma_H \right) \frac{(1 + \phi)\alpha_H(n_X + n_H)}{\Gamma\Theta} \right] \left(\frac{n_X \hat{a}_X + n_H \hat{a}_H}{n_X + n_H} \right) \\
 &- \left(\frac{\phi + \sigma}{\Theta} \frac{n_H}{n_X + n_H} + \left(\frac{\alpha(1 - \sigma)}{\Theta} \right) (1 - \gamma_X)\gamma_H \right) \frac{1}{\Gamma} \hat{a}_H.
 \end{aligned}$$

Recalling $\alpha_X = \frac{n_X}{n_X + n_H} - \gamma_X$, and $\alpha_H = \frac{n_H}{n_X + n_H} - (1 - \gamma_X)\gamma_H$, one also has

$$\begin{aligned}
 \Psi &= \left[\frac{(\phi + \sigma)(1 - \alpha)}{\alpha\Theta} + \frac{(1 + \phi)}{\Theta} \left(\frac{(1 - \gamma_X)\gamma_H(n_X + n_H)}{n_H} \right) \right] \frac{n_X}{(n_X + n_H)} \\
 &+ \left(1 - \frac{(1 - \gamma_X)\gamma_H(n_X + n_H)}{n_H} \right) \left(\frac{(1 - \alpha)(1 - \sigma)}{\Theta} \gamma_X \right) \\
 &= \frac{(1 - \gamma_X)\gamma_H(n_X + n_H)}{n_H} \left[\gamma_X + \frac{(1 + \phi)}{\Theta} \alpha_X \right] + \frac{(1 - \alpha)}{\Theta} \left[(1 - \sigma)\gamma_X + \frac{(\phi + \sigma)}{\alpha} \frac{n_X}{(n_X + n_H)} \right] \\
 \Gamma_i &= \left(\frac{1}{\alpha} - \frac{(1 + \phi)}{\Theta} \right) \frac{n_X}{n_X + n_H} + \frac{(1 + \phi)}{\Theta} \left(\frac{n_X}{n_X + n_H} + \frac{n_H}{n_X + n_H} - (1 - \gamma_X)\gamma_H \right) + \eta - 1 \\
 &= \frac{(1 - \alpha)(\phi + \sigma)}{\alpha\Theta} \frac{n_X}{n_X + n_H} + \frac{(1 + \phi)}{\Theta} (1 - (1 - \gamma_X)\gamma_H) + \eta - 1.
 \end{aligned}$$

Thus, Ψ , Γ_i , and Γ are positive. Furthermore, numerical approximations show that

$$\frac{\Psi}{\Gamma}$$

increases, and

$$\alpha_X + \alpha_H \frac{\Psi}{\Gamma}$$

decreases with γ_H . It follows that the elasticity,

$$\left[\frac{\phi + \sigma}{\Theta} \alpha_X - (1 - \gamma_X) + \left[\frac{\phi + \sigma}{\Theta} \frac{n_H}{n_X + n_H} + \left(\frac{\alpha(1 - \sigma)}{\Theta} \right) (1 - \gamma_X) \gamma_H \right] \frac{\Psi}{\Gamma} \right]$$

of

$$\frac{W}{P_X}$$

with respect to $\frac{P_X}{P}$, which is negative, is larger in absolute value as γ_H decreases.

Note too that Ψ is independent of, while Γ_1 and Γ increase with, the elasticity of substitution η . Thus

$$\frac{\Psi}{\Gamma} \text{ and } \alpha_X + \alpha_H \frac{\Psi}{\Gamma}$$

decrease with η .

One-sector economy with fixed costs in production

Flexible wages

Claim: The larger the number, n , of firms in operation, the higher the demand for labour and the higher the real wage.

Recall the expression for the markup,

$$D \left[\frac{P_X}{W} \right]^{-\frac{\alpha + \varphi}{\alpha \sigma}} = n^{\frac{\varphi}{\sigma}} \left(\frac{n}{1 - \alpha} A_X^{\frac{1}{\alpha}} \left[\frac{P_X}{W} \right]^{\frac{1 - \alpha}{\alpha}} - \text{totc} \right),$$

$$D = \left(\frac{\lambda}{\lambda - 1} \right)^{-\frac{1}{\sigma} - \frac{\varphi}{\alpha \sigma}} A_X^{\frac{1}{\alpha}} \left(\frac{P_X}{P} \right)^{\frac{(1 - \sigma)}{\sigma}}.$$

Differentiating both sides with respect to n , and letting d denote the partial derivative of

$$\frac{P_X}{W},$$

we obtain

$$D\left(-\frac{\alpha+\varphi}{\alpha\sigma}\right)\left[\frac{P_X}{W}\right]^{-\frac{\alpha+\varphi}{\alpha\sigma}-1}d = \frac{\varphi}{\sigma}n^{-1}D\left[\frac{P_X}{W}\right]^{\frac{\alpha+\varphi}{\alpha\sigma}} \\ + n^{\frac{\varphi}{\sigma}}\left[\frac{1}{1-\alpha}A_X^{\frac{1}{\alpha}}\left[\frac{P_X}{W}\right]^{\frac{1-\alpha}{\alpha}} + \frac{1-\alpha}{\alpha}\frac{n}{1-\alpha}A_X^{\frac{1}{\alpha}}\left[\frac{P_X}{W}\right]^{\frac{1-\alpha}{\alpha}-1}d - \frac{\partial}{\partial n}totc\right],$$

hence

$$d\left[\frac{P_X}{W}\right]^{-1}\left[D\left(-\frac{\alpha+\varphi}{\alpha\sigma}\right)\left[\frac{P_X}{W}\right]^{-\frac{\alpha+\varphi}{\alpha\sigma}-1} - n^{\frac{\varphi}{\sigma}}\frac{1}{\alpha}A_X^{\frac{1}{\alpha}}\left[\frac{P_X}{W}\right]^{\frac{1-\alpha}{\alpha}}\right] = \frac{\varphi}{\sigma}n^{-1}D\left[\frac{P_X}{W}\right]^{\frac{\alpha+\varphi}{\alpha\sigma}} \\ + n^{\frac{\varphi}{\sigma}}\left[\frac{1}{1-\alpha}A_X^{\frac{1}{\alpha}}\left[\frac{P_X}{W}\right]^{\frac{1-\alpha}{\alpha}} - \frac{\partial}{\partial n}totc\right],$$

hence,

$$d\left[\frac{P_X}{W}\right]^{-1}\left[(-n)A_X^{\frac{1}{\alpha}}\left[\frac{P_X}{W}\right]^{\frac{1-\alpha}{\alpha}}\left(\frac{\alpha+\varphi+(1-\alpha)\sigma}{(1-\alpha)\sigma}\right) + \frac{\alpha+\varphi}{\sigma}totc\right] \\ = \frac{\varphi}{\sigma}n^{-1}\left(\frac{n}{1-\alpha}A_X^{\frac{1}{\alpha}}\left[\frac{P_X}{W}\right]^{\frac{1-\alpha}{\alpha}} - totc\right) + \left[\frac{1}{1-\alpha}A_X^{\frac{1}{\alpha}}\left[\frac{P_X}{W}\right]^{\frac{1-\alpha}{\alpha}} - \frac{\partial}{\partial n}totc\right]$$

hence,

$$-d\left[\frac{P_X}{W}\right]^{-1}\left[n\left(\frac{\tilde{c}}{\alpha} + k\right)(1-\alpha) + \frac{\alpha+\varphi}{\sigma}\left(n\frac{\tilde{c}}{\alpha} - totc + nk\right)\right] \\ = \frac{\varphi}{\sigma}n^{-1}\left[n\frac{\tilde{c}}{\alpha} - totc + nk\right] + \left[\frac{\tilde{c}}{\alpha} + k - \frac{\partial}{\partial n}totc\right],$$

where $\tilde{c}$ is the largest fixed cost of a firm that is in operation and

$$k \equiv \frac{1}{1-\alpha}A_X^{\frac{1}{\alpha}}\left(\frac{P_X}{W}\right)^{\frac{1-\alpha}{\alpha}} - \frac{\tilde{c}}{\alpha}.$$

Note, $totc \leq n\bar{c} \leq \frac{n\bar{c}}{\alpha}$, $k \geq 0$ (otherwise a firm with fixed cost $\bar{c}$ would not produce), and

$$\frac{\partial}{\partial n} totc \geq \bar{c},$$

since all firms with fixed cost less than $\bar{c}$ must already be in operation. Thus, all the terms in brackets in the equation above are positive, and d is negative. In other words, a marginally lower number of firms in operation leads to a higher markup, which in turn implies higher, hence non-negative, profits. It follows that, as claimed, the lower the number of firms in operation, the higher the markup and the lower the real wage.

Claim: Suppose that firms' fixed costs are distributed uniformly on the interval $[0, 1]$. Then the markup grows faster with changes in relative prices once the economy is at full capacity, i.e., once all the firms are in operation.

Indeed, if n is the number of firms in operation, then the highest fixed cost of a firm that does produce output is n and

$$totc = \frac{n^2}{2}.$$

Recall that

$$n^\varphi \left(\frac{n\bar{c}}{\alpha} - totc \right)^\sigma = \left(\frac{\lambda-1}{\lambda} \right) \left(\frac{1-\alpha}{\alpha} \bar{c} \right)^{\frac{-(\alpha+\varphi)}{1-\alpha}} A_X^{\frac{(1+\varphi)}{1-\alpha}} \left(\frac{P_X}{P} \right)^{(1-\sigma)},$$

It follows

$$n^\varphi \left(\frac{n^2}{\alpha} - \frac{n^2}{2} \right)^\sigma = \left(\frac{\lambda-1}{\lambda} \right) \left(\frac{1-\alpha}{\alpha} n \right)^{\frac{-(\alpha+\varphi)}{1-\alpha}} A_X^{\frac{(1+\varphi)}{1-\alpha}} \left(\frac{P_X}{P} \right)^{(1-\sigma)},$$

hence

$$n^{\frac{(\alpha+\varphi)+(2\sigma+\varphi)(1-\alpha)}{1-\alpha}} \left(\frac{1}{\alpha} - \frac{1}{2} \right)^\sigma = \left(\frac{\lambda-1}{\lambda} \right) \left(\frac{1-\alpha}{\alpha} \right)^{\frac{-(\alpha+\varphi)}{1-\alpha}} A_X^{\frac{(1+\varphi)}{1-\alpha}} \left(\frac{P_X}{P} \right)^{(1-\sigma)},$$

as long as this number is smaller than the total number of firms in the sector. It follows that a 1 per cent increase in the relative price

$$\frac{P_X}{P}$$

raises the number of firms by

$$\frac{(1-\sigma)(1-\alpha)}{(\alpha+\phi)+(2\sigma+\phi)(1-\alpha)}$$

and the markup by

$$\frac{\alpha(1-\sigma)}{(\alpha+\phi)+(2\sigma+\phi)(1-\alpha)},$$

as long as some capacity is idle. Whereas, once the economy reaches capacity, the markup grows by

$$\frac{\alpha(1-\sigma)}{(\alpha+\phi) + \frac{\frac{1}{1-\alpha} A_X^{\frac{1}{\alpha}} \left[\frac{P_X}{W} \right]^{\frac{1-\alpha}{\alpha}}}{\frac{1}{1-\alpha} A_X^{\frac{1}{\alpha}} \left[\frac{P_X}{W} \right]^{\frac{1-\alpha}{\alpha}} - \frac{1}{2}}} \sigma(1-\alpha)$$

which ranges over the interval

$$\left[\frac{\alpha(1-\sigma)(2-\alpha)}{(2-\alpha)(\alpha+\phi)+2\sigma(1-\alpha)}, \frac{\alpha(1-\sigma)}{(\alpha+\phi)+\sigma(1-\alpha)} \right],$$

since

$$\frac{\frac{\frac{1}{1-\alpha} A_X^{\frac{1}{\alpha}} \left[\frac{P_X}{W} \right]^{\frac{1-\alpha}{\alpha}}}{\frac{1}{1-\alpha} A_X^{\frac{1}{\alpha}} \left[\frac{P_X}{W} \right]^{\frac{1-\alpha}{\alpha}} - \frac{1}{2}}}{\frac{1}{1-\alpha} A_X^{\frac{1}{\alpha}} \left[\frac{P_X}{W} \right]^{\frac{1-\alpha}{\alpha}} - \frac{1}{2}}$$

ranges over

$$\left[1, \frac{2}{2-\alpha} \right] \text{ as } \frac{1}{1-\alpha} A_X^{\frac{1}{\alpha}} \left[\frac{P_X}{W} \right]^{\frac{1-\alpha}{\alpha}} \geq \frac{1}{\alpha}.$$

In particular, the markup grows more rapidly once the economy reaches capacity.

Predetermined wages

Claim: Assuming firms' fixed costs are distributed uniformly on the interval $[0,1]$, a negative shock to the terms of trade calls for a smaller expansion in the money supply when the economy is at full capacity than when it is below capacity.

From the market equilibrium,

$$C = \frac{n}{1-\alpha} \left(A_X \frac{P_X}{P} \right)^{\frac{1}{\alpha}} \left[\frac{P}{W} \right]^{\frac{1-\alpha}{\alpha}} - \frac{P_X}{P} totc.$$

Substituting this expression into $M = \chi PC^\sigma$, it follows that

$$M = \chi \left[\frac{P_X}{P} \right]^{\sigma-1} \left[\frac{n}{1-\alpha} A_X^{\frac{1}{\alpha}} \left[\frac{P_X}{W} \right]^{\frac{1-\alpha}{\alpha}} - totc \right]^\sigma \frac{P_X}{W} W.$$

When the economy is at full capacity, the markup under flexible wages satisfies

$$\left(\frac{\bar{n}}{1-\alpha} A_X^{\frac{1}{\alpha}} \left[\frac{P_X}{W} \right]^{\frac{1-\alpha}{\alpha}} - totc \right) = \left(\frac{\lambda}{\lambda-1} \right)^{\frac{1}{\sigma}} A_X^{\frac{\frac{\varphi}{\alpha\sigma}}{\sigma}} \left(\frac{P_X}{P} \right)^{\frac{(1-\sigma)}{\sigma}} \left[\frac{P_X}{W} \right]^{\frac{-\alpha+\varphi}{\alpha\sigma}} \bar{n}^{-\frac{\varphi}{\sigma}},$$

hence

$$M = \chi \left(\frac{\lambda}{\lambda-1} \right)^{-1} A_X^{\frac{\frac{\varphi}{\alpha}}{\alpha}} \left[\frac{P_X}{W} \right]^{\frac{\frac{\varphi}{\alpha}}{\alpha}} \bar{n}^{-\varphi} W,$$

and therefore the money supply must expand by $\frac{\varphi}{\alpha}$ the percentage drop of the markup in response to a change in relative prices. It follows from the previous results that the money supply should expand by at most

$$\frac{\varphi(1-\sigma)}{(\alpha+\varphi)+\sigma(1-\alpha)}.$$

Whereas, when the economy is below capacity,

$$\frac{P_X}{W} = \left(\frac{1-\alpha}{\alpha} \bar{c} \right)^{\frac{\alpha}{1-\alpha}} A_X^{-\frac{1}{1-\alpha}},$$

hence

$$M = \chi \left[\frac{P_X}{P} \right]^{\sigma-1} \left[\frac{nc}{\alpha} - totc \right] \frac{\sigma P_X}{W} W = \chi \left[\frac{P_X}{P} \right]^{\sigma-1} \left[\frac{(2-\alpha)n^2}{2\alpha} \right] \frac{\sigma P_X}{W} W,$$

and therefore the money supply must expand by $\frac{\phi}{\alpha}(2-\alpha)$ the percentage drop of the markup in response to a change in relative prices, hence by

$$\frac{\phi(2-\alpha)(1-\sigma)}{(\alpha+\phi)+(2\sigma+\phi)(1-\alpha)},$$

which is greater than the upper bound in the case where the economy is at full capacity.

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Discussion

Craig Burnside

Gabriel Srouf presents an interesting paper on the effectiveness of monetary policy in a relatively small open economy such as Canada's. He concentrates on theoretical modelling and considers three models, all of which are single-period static models:

- a baseline model in which there is one domestically produced good, called a primary good, and one foreign-produced good;
- an expanded model in which there are two domestically produced goods (the primary good and another good, which is highly substitutable with foreign-produced goods), and one foreign-produced good;
- a model in which there are fixed costs of production. This model is equivalent in other respects to the baseline model.

As the introduction indicates, the author compares these models in an attempt to shed light on four developments in the Canadian economy over the past several decades:

- a decline in the share of primary goods in Canada's trade;
- a secular decline in the relative price of primary goods;
- increased labour mobility;
- a decline in exchange rate pass-through.

A decline in the share of primary goods in trade is captured in a rather brute-force way through the introduction of the second domestic good in the expanded model versus the baseline model. Increased labour mobility is captured by considering two versions of the expanded model. In one version, labour is assumed to be perfectly mobile across sectors, so that there is a single labour market. In the other version, each worker is assumed

to be associated with one sector or another, and cannot change sectors in response to shocks. Most models in the paper consider the case where all relative prices are determined abroad, all goods are tradable, and purchasing-power parity (PPP) holds for all goods. By considering an example where the relative price of one of the domestic goods is determined endogenously, the effects of variable exchange rate pass-through can also be examined. The paper does not really have anything to say about the effects of a downward trend in the relative price of primary goods.

In comparing models, the author consistently asks the following question: "When wages are set in advance, is monetary policy able to replicate the equilibrium that would result if wages were flexible?" The author also provides solutions for the size of the monetary policy response that is needed to obtain the flexible-wage equilibrium. The answer to the question posed above is "yes" for the baseline model, "yes" for the expanded model if labour is mobile, "no" for the expanded model if labour is immobile, and "it depends" for the model with fixed costs.

My comments on the paper focus on providing intuition for the basic results for the baseline and expanded models. I will show that the model always boils down to four equations that can be understood in a simple supply and demand diagram.

Since the model in the paper is static, we can think of any standard model in which households maximize their utility by choosing consumption and labour supply subject to a budget constraint. In the model, consumption is a basket of goods, but this adds a layer of complication from which we can abstract. For my purposes, the household's utility is

$$U = \frac{1}{1-\sigma} C^{1-\sigma} - \frac{1}{1+\phi} N^{1+\phi} + \chi \ln(M/P), \quad (1)$$

and, in equilibrium, the household's budget constraint is

$$C = \text{real wages} + \text{real profits}, \quad (2)$$

where C is a consumption aggregate, N is household labour supply, M is nominal money balances, and P is the domestic price level.

1 The Baseline Model

1.1 Flexible wages

Wage-setting equation. In the baseline model, there is only one domestically produced good, so real wages are just wN , where w is the real wage

rate. In standard dynamic macro models, there is an intratemporal Euler equation that sets the marginal utility of leisure equal to the marginal utility of consumption times the real wage. The model in this paper is slightly different, because households are price-setters (monopolistic competitors) in labour markets.¹ Hence, the following first-order condition holds:

$$-U_N = U_C w(1 - 1/\lambda), \quad (3)$$

where U_N and U_C represent the partial derivatives of the utility function with respect to labour and consumption, and $\lambda > 1$ is the elasticity of substitution between different types of labour. In a model of perfect competition, we would simply have $\lambda = \infty$. Of course, given the utility function in equation (1), equation (3) can be rewritten as

$$C^\sigma N^\phi = w(1 - 1/\lambda), \quad (4)$$

This wage-setting equation can be used to express w as a function of N , with C as a shifter.

Budget constraint. Since the value of all domestically produced output is distributed to domestic households either as wages or as profits, if we assume that the output of the domestic good is

$$Y = AN^{1-\alpha}/(1-\alpha), \quad (5)$$

then equation (2), the budget constraint, can be rewritten as

$$C = pAN^{1-\alpha}/(1-\alpha), \quad (6)$$

where p is the price of the domestic good relative to the overall price level.² This relative price is set in world markets, so if we combine equations (4) and (6), we get the **labour supply curve**.

$$w = \frac{\lambda}{\lambda-1} \left(\frac{A}{1-\alpha} \right)^\sigma p^\sigma N^{(1-\alpha)\sigma+\phi}, \quad (7)$$

which is a simple upward sloping function with p as an exogenous shifter.

1. The labour market is structured in this way to facilitate the modelling of forward-looking wage-setting when we look at the case where wages are set in advance.

2. That is, p is equal to P_X/P , where P_X is the domestic price of the domestic good, and P is a price aggregator that combines the price of domestic goods, P_X , and the domestic price of foreign goods, P_F . Since PPP holds for all goods, p is determined by relative prices in the world market.

Labour demand curve. Firms are price-takers in labour markets and maximize real profits given by $\pi = pY - wN$. Hence, they set N consistent with the relative wage being equal to the marginal product of labour:

$$w = pAN^{-\alpha}. \quad (8)$$

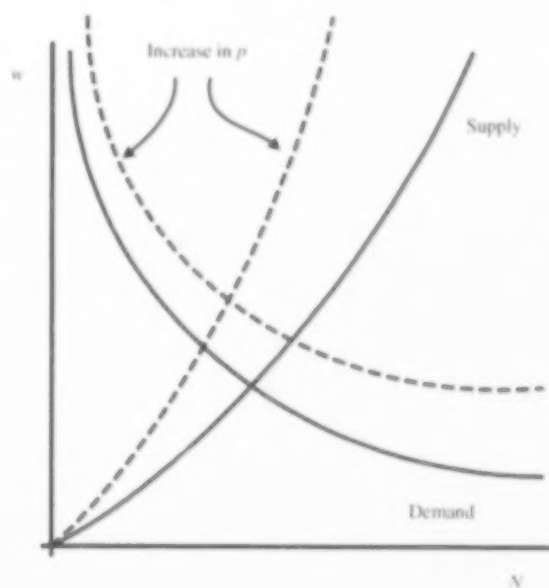
This is a simple downward sloping function with p as an exogenous proportional shifter.

Equilibrium is determined by labour supply equalling labour demand. As we can see from combining equations (7) and (8) and from Figure 1, the equilibrium quantity of N depends on p and is equal to

$$N^*(p) = \left[\frac{\lambda - 1}{\lambda} (1 - \alpha)^{\sigma} (pA)^{1 - \sigma} \right]^{1 / [(1 - \alpha)\sigma + \phi + \alpha]}. \quad (9)$$

Figure 1

Equilibrium in the flexible-wage model



The equilibrium values of the real wage and consumption can then be found by substituting N^* into equations (6) and (8).

Money demand. There is no interesting role for monetary policy in the flexible-price model. The first-order condition for money balances implies $M = \chi PC$ or

$$M/S = \chi P^w C, \quad (10)$$

where P^w is the price aggregator evaluated at world prices (which are exogenous). Hence, in a flexible exchange rate regime, where M is set by the monetary authority, S responds passively to make equation (10) hold. In a fixed exchange rate regime, M responds passively to make equation (10) hold. But the effects of monetary policy are completely contained within equation (10); money has no real effect.

1.2 Wages set in advance

When nominal wages are set in advance, the only change is that the wage-setting equation is replaced by an expectational version of equation (3):

$$-E(U_N) = W(1 - 1/\lambda)E(U_C/P), \quad (11)$$

where W is the nominal wage. Rather than formally analyze this equation, I simplify by replacing the wage-setting equation by $W = W_0$, where W_0 is some arbitrary value of the nominal wage.³ The labour market clears by assuming that households satisfy labour demand at W_0 .

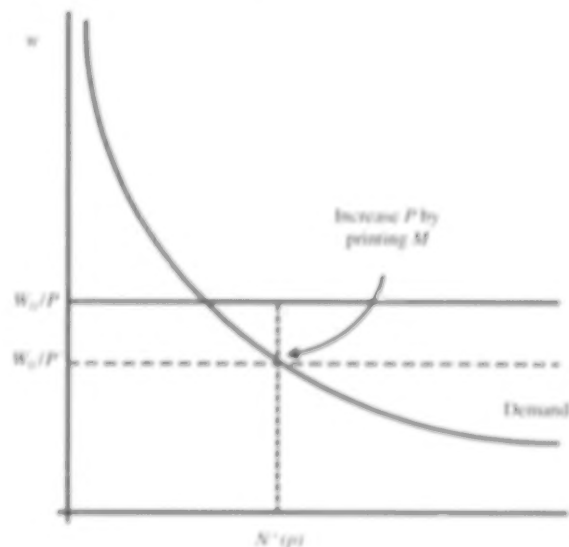
Since the nominal wage is predetermined, it is clear that consumption, labour, and the price level (or equivalently, the exchange rate) will be determined jointly by our other three equations: (6), (8), and (10). As Figure 2 shows, as long as the monetary authority can manipulate the price level for a given value of W_0 and p , the horizontal supply schedule can be made to intersect the demand schedule at any quantity, including the flexible-price equilibrium quantity, $N^*(p)$.

How does the monetary authority manipulate the price level in exactly the right way? This can be determined by solving equations (6), (8), and (10) under the assumption that $N = N^*(p)$. It is easy to show that:

$$M = \chi N^*(p) W_0 / (1 - \alpha). \quad (12)$$

3. The spirit of my discussion is not changed if one assumes that W_0 is an optimal choice of preset nominal wage consistent with equation (11).

Figure 2
Equilibrium when wages are set in advance



Note that with this monetary policy, equilibrium consumption is also equal to the same value as in the flexible-wage equilibrium.

One way of thinking about the magnitude of the required monetary policy response is to measure the change in the money supply that is required as the result of any unanticipated change in the terms of trade, p . Since the desired money supply is proportional to $N^*(p)$, this can be measured in terms of the elasticity of $N^*(p)$ with respect to p , which is easily obtained from equation (9).

While replication of the flexible-wage equilibrium is interesting, it might also be useful to consider other monetary policies. For example, it might be constructive to establish whether there is a monetary policy that can offset the effects of imperfect competition in labour markets.

2 The Expanded Model

2.1 Mobile labour

The assumption that labour is mobile between sectors means that labour must be paid the same wage regardless of which sector it works in. Hence, despite the fact that there are two different goods being produced in the domestic economy, there is a single domestic labour market.

Wage-setting works exactly as it did before, so that equation (3) still holds. The budget constraint works a little differently and is now given by

$$C = p_X A_X N_X^{1-\alpha} / (1-\alpha) + p_H A_H N_H^{1-\alpha} / (1-\alpha), \quad (13)$$

where X and H represent the two goods whose prices relative to the consumption price index are $p_X = P_X/P$ and $p_H = P_H/P$, respectively. As we will see, the share of the labour supply that works in sector X , which I denote $x = N_X/N$, will be a function only of p_X and p_H , which are set in world markets. I denote this function $x = x(p_X, p_H)$. Hence, we can write equation (13) as

$$C = [p_X A_X x^{1-\alpha} + p_H A_H (1-x)^{1-\alpha}] N^{1-\alpha} / (1-\alpha). \quad (14)$$

Combining this expression with equation (3), we obtain a labour supply schedule much like we have for the basic model in Figure 1. The key difference is that this labour supply schedule is buffeted by shocks to two relative prices, p_X and p_H , instead of just one.

The labour demand schedule works exactly as before, except that there are two goods; hence, equation (8) holds for each good:

$$w = p_X A N_X^{-\alpha} = p_H A N_H^{-\alpha}. \quad (15)$$

Note that it follows from equation (15) that

$$x = \frac{(p_X A_X)^{1/\alpha}}{(p_X A_X)^{1/\alpha} + (p_H A_H)^{1/\alpha}}, \quad (16)$$

and that the labour demand curve is

$$w = p_X \bar{L}^{-\alpha} A_X N^{-\alpha}. \quad (17)$$

This is only slightly different from the demand schedule in Figure 1 in that, like the supply curve, it is affected by shocks to two relative prices instead of one.

Given that the demand and supply for labour still appear as they do in Figure 1, but are buffeted by more shocks, one's intuition would be that under sticky nominal wages, monetary policy could still achieve the flexible-price equilibrium as long as the price level could be manipulated. The reason is straightforward: there is a single labour market. Hence, for any W_0 , monetary policy can manipulate the real wage so that the aggregate quantity of labour is the same as in the flexible-wage equilibrium. The allocation of labour across sectors will be the same as well, because labour is fully mobile.

The monetary policy rule that achieves the flexible-price equilibrium is similar to the one in the baseline model, except that it depends on both relative prices. In particular, if the flexible-wage equilibrium level of labour supply is $N^*(p_X, p_H)$, then equations (10), (14), and (15) can be solved assuming $N = N^*(p_X, p_H)$ to obtain the appropriate expression for M .

2.2 Immobile labour

The model of immobile labour assumes that certain households or members of households are associated with particular production sectors. The paper does not make clear precisely how this is modelled. Are there different types of workers within the household? Do households share the proceeds of their work effort and profits from ownership of the firms in a common pool of resources so that consumption is identical across individuals? This seems to be the implicit assumption in the paper, but I make it my working assumption here. I assume that the household divides up into X workers and H workers at the beginning of the period, where each group makes separate wage-setting decisions, understanding the resource pooling that will occur later. This means that the labour supply curves in the two sectors have the same shape and only differ depending on the arbitrary allocation of workers across sectors.

Because labour is not mobile, nothing requires the equilibrium real wage to be equal across sectors. Hence, there are two separate labour demand curves. We therefore end up with two diagrams that resemble Figure 1, one for each sector.

When wages are established in advance in this setting, monetary policy will no longer be able to replicate the flexible-wage equilibrium. The reason is straightforward. Monetary policy could attempt to replicate the flexible-wage equilibrium in one of the two labour markets, but not in both. It could

also try to replicate the outcome for total labour supply. But since monetary policy, through its manipulation of the price level, is a single instrument, it cannot fully achieve two potentially conflicting outcomes in the two labour markets.

Concluding Remarks

The paper presents an interesting set of models that allow us to compare the efficacy of monetary policy in different economic environments for a small open economy. The paper shows that when prices are set in advance, the ability of monetary policy to replicate the flexible-wage equilibrium depends on whether there are multiple sectors in the model, and labour mobility across sectors. In particular, the flexible-wage equilibrium can be achieved as long as labour is fully mobile. If there are costs of adjusting the sectoral allocation of labour, then the flexible-wage equilibrium cannot be fully replicated in a multi-sector model.

Future research would do well to assess the importance of these findings quantitatively. In reality, Canada's economy has always had multiple sectors. Furthermore, there has always been some degree of labour mobility. How monetary policy has been affected by these changes over time would require a modelling framework in which we could think less starkly about the diversification of Canada's economy and the changes in its labour markets. Future research would also need to discuss the changing nature of wage-setting in the Canadian economy, and the changing instruments of monetary policy.

In sum, I am suggesting that future research should focus on empirical assessments of the issues that Sroul raises. His theoretical results are interesting—but their importance demands a closer, more empirical investigation.

General Discussion*

Participants focused their comments primarily on Canadian policy issues. David Laidler was skeptical about the paper's fixed-cost assumption. He related it to what he considered the assumption of "laziness" by some authors, and he argued that such an assumption is more plausible in the manufacturing sector than in the primary sector. Consequently, he felt that an expanded model with fixed costs embedded in the manufacturing sector would be more useful in the Canadian policy context.

Michael Devereux appreciated the model's fixed-cost characteristic, because he saw it as capturing bankruptcy considerations or irreversibility aspects that current macro models may be missing. Gabriel Sroul explained that differences in fixed costs could be explained by the inability of firms to change rapidly. Thus, fixed costs represent certain rigidities of process rather than "laziness." Under this assumption, the model showed that monetary policy will sometimes encourage less efficient firms to overproduce and more productive firms to underproduce. Sroul agreed that this idea of efficiency could be important when looked at between two sectors.

Devereux emphasized Laidler's concern about investigating the appropriate sector and addressed Cédric Tille's work regarding shocks that hit one sector relative to another. Devereux commented that having many different types of shocks becomes problematic for monetary policy, given one policy tool, but he felt that this model could be used to analyze such questions. Sroul acknowledged Tille's contribution to his own analysis of the effects of elasticity of substitution between sectors.

* Prepared by Jeremy Friesen and James Rossiter.

Laidler suggested that another important policy question is exchange rate sensitivity to commodity prices, given a possible secular decline of commodity export dependence. The thought was that intersectoral labour mobility would be a useful tool with which to approach this question. He further suggested that the model be expanded to look at the effects of international labour mobility in addition to sectoral labour mobility. He saw the need for the model to reflect *varying degrees* of mobility rather than full mobility or none at all. Srour stated that he too was interested in international labour mobility being incorporated into the model, but thought that perhaps it was less of a current policy concern for Canada.

Devereux questioned the use of a flexible-wage equilibrium as a valid benchmark, citing recent work by Obstfeld and Rogoff. Srour addressed this point by noting that the mathematical solution to the welfare-maximizing equilibrium could have been used as a benchmark and, in fact, the two did yield dissimilar results in the model, although they were equal in some specifications. It was Srour's view, however, that monetary policy should try to replicate market conditions and that any welfare-optimization issue was not clearly a monetary policy problem and could be dealt with in another policy form and with other policy tools.

Price-Setting and Exchange Rate Pass-Through: Theory and Evidence

*Michael B. Devereux and James Yetman**

Introduction

In the early years of floating exchange rates, economists expected to find a close association between movements in exchange rates and national price levels. Based on the presumption of approximate purchasing-power parity, it was felt that control of domestic inflation would become more problematic in an environment of exchange rate volatility. However, a substantial literature, covering many countries, has documented that exchange rate changes are, at best, weakly associated with changes in domestic prices at the consumer level. The low degree of "exchange rate pass-through" both at the disaggregated level, for individual traded goods prices, and more generally, in aggregate price indexes, has been extensively documented.¹

A debate on the causes of low exchange rate pass-through has recently begun. Some writers argue that the ultimate explanation is microeconomic, based on various structural features of international trade, such as pricing to market by imperfectly competitive firms (Corsetti and Dedola 2002), domestic content in the distribution of traded goods (Corsetti and Dedola 2002; Burstein, Neves, and Rebelo 2000), the importance of non-traded goods in consumption (Betts and Kehoe 2001), or the role of substitution

1. See, for instance, Engel (2002b).

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between goods in response to exchange rate changes (Burstein, Eichenbaum, and Rebelo 2002). Others argue, however, that the failure of pass-through is more of a macroeconomic phenomenon, related to the slow adjustment of goods prices at the consumer level (Engel 2002 a, b). Campa and Goldberg (2002) provide evidence for OECD countries that both factors are important in the evolution of exchange rate pass-through estimates over time, but they ultimately come down on the side of a microeconomic explanation, based on the changing composition of import goods.

Whether the behaviour of exchange rate pass-through is attributed to sticky prices or to more structural features of international trade is important. For example, if pass-through is systematically related to monetary policy, as suggested by Taylor (2000), this would have significant implications for the appropriate way to conduct monetary policy in an open economy.

In this paper, we develop a simple framework within which to investigate the importance of slow price adjustment in explaining exchange rate pass-through in an open economy. Our empirical approach closely follows Ball, Mankiw, and Romer (1988), and borrows their methodology for testing the role of sticky prices in explaining the differing slopes of estimated Phillips curves in cross-country data. Based on our theoretical model and the empirical evidence, we argue that sticky prices play an important role in cross-country variations in exchange rate pass-through. As a result, we argue that exchange rate pass-through is endogenous to the monetary policy regime.

We first develop a simple theoretical model of endogenous exchange rate pass-through. The model abstracts from many factors that might limit pass-through, and focuses exclusively on the role of price rigidities that come about because of the presence of "menu costs." Modelling monetary policy as a "Taylor-type" interest rate rule, we show that monetary policy determines both the average rate of inflation and the volatility of the nominal exchange rate. Exchange rate pass-through is determined by the types of shocks in the economy, and their persistence. But with a constant frequency of price changes, pass-through is independent of monetary policy.

We go on to allow firms to determine the frequency with which prices change. This frequency is chosen as a result of the trade-off between the menu costs of price change and the loss from being away from the optimal desired price. In general, the optimal frequency of price changes will vary with the monetary policy regime. For a given size of the menu cost of price changes, firms will choose a higher frequency of price adjustment—the higher the average rate of inflation, the more volatile the nominal exchange rate; and the higher the frequency of price changes, the greater the exchange rate pass-through. In a calibration of our model, we find that for annual rates

of inflation higher than 25 per cent, firms will adjust prices every period so that price rigidity disappears completely. In that case, the pass-through from exchange rate changes to prices is complete.

In our empirical implementation of the model, we estimate simple aggregate pass-through coefficients for 122 countries. A closely related paper by Choudhri and Hakura (2001) shows that estimated exchange rate pass-through tends to vary systematically with the mean inflation rate. For countries with very high inflation rates, we find, as in Choudhri and Hakura, that aggregate pass-through is very high, and in many cases statistically indistinguishable from unity. We then show that there is a non-linear relationship between estimated pass-through coefficients and average inflation rates. As inflation rises, pass-through rises, but at a declining rate. These results offer *prima facie* evidence of the importance of sticky prices in determining the average rate of pass-through. For countries with very high inflation, prices become essentially flexible, the cost to firms of maintaining fixed prices fully offsetting the menu costs of price changes, and exchange rate pass-through is complete.

The rest of the paper is arranged as follows. Section 1 documents the price-setting problem facing a single firm. Section 2 integrates this into a model of exchange rate determination. Section 3 investigates the determinants of exchange rate pass-through within the model. Section 4 allows for an endogenous frequency of price adjustment. Section 5 presents the empirical results, and the final section concludes.

1 The Importing Firm

In this section, we derive the optimal pricing policy for a firm, given an exogenous frequency of price-setting. This essentially follows the Calvo (1983) model, save for the fact that the firm is an importer rather than a producer. Consider a set of domestic firms that import a consumer good from abroad and sell it to local consumers. Each firm has marginal costs of P_t^* in terms of foreign currency. Suppose that each individual firm, i , selling to the domestic market faces demand given by

$$C_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\lambda} C_t,$$

where $P_t(i)$ is the firm's price, and P_t is the composite price index for foreign goods sold on the domestic market (this demand function will be derived from the domestic country's utility maximization—see below). The firm's profit at any period t is then given by

$$\Pi_t(i) = P_t(i)C_t(i) - S_t P_t^* C_t(i).$$

Here, S_t is the exchange rate. By assumption, the firm sets prices in terms of the domestic currency. If the firm could freely adjust its price at any time, it would set the price equal to the desired price, $\hat{P}_t(i)$, given by

$$\hat{P}_t(i) = \frac{\lambda}{\lambda-1} S_t P_t^*.$$

However, suppose that there is some menu cost, F , that must be paid by the firm whenever it changes its price, where F is measured as a fraction of steady-state profits. As in Calvo (1983), we assume that there is a probability of $1 - \kappa$ that the firm changes its price at any period, and thus a probability of κ that the firm's price will remain unchanged, *no matter how long* it has been fixed. In section 4, we will allow the probability of price changes to be endogenous.

How do we determine what price the firm will set? As has been shown in many papers (e.g., Walsh 1998), the intertemporal profit-maximization condition of the firm may be approximated as a negative function of the expected squared deviation of the log price from the desired log price in each period. Thus, the firm's objective function can be written as a *loss function*, given by

$$L_t = F + E_t \left[\sum_{j=0}^{\infty} (\beta\kappa)^j (\tilde{p}_t(i) - \hat{p}_{t+j}(i))^2 + \frac{(1-\kappa)}{\kappa} \sum_{j=1}^{\infty} (\beta\kappa)^j L_{t+j} \right],$$

where lower-case letters represent logs. Here, L_t represents the proportional difference between unconstrained profits, when the firm adjusts its price in every period, and actual profits, when the firm sets its price at time t , under the assumptions of the Calvo model, including the menu cost of price change, F .² The total loss, L_t , comprises the immediate loss of F , interpreted as the share of average profits going to price adjustment, and the expected discounted value of losses from having the newly set price, $\tilde{p}_t(i)$, differ from the desired price, $\hat{p}_{t+j}(i)$, plus the expected value of the loss function that applies when the firm will be able to change its price again in the future, which happens each period with probability $1 - \kappa$.

It is straightforward to show that the optimal price for the newly price-setting firm obeys the recursive equation

2. In this section, the menu cost is irrelevant to the firm's decision-making. But when κ is endogenous, the menu cost becomes critical.

$$\tilde{p}_t(i) = (1 - \beta\kappa)\tilde{p}_t + \beta\kappa E_t \tilde{p}_{t+1}(i).$$

From the definition of $\tilde{p}_t$, this implies that

$$\tilde{p}_t(i) = (1 - \beta\kappa)(\hat{\lambda} + s_t + p_t^*) + \beta\kappa E_t \tilde{p}_{t+1}(i), \quad (1)$$

where $\hat{\lambda} = \ln(\lambda/(\lambda - 1))$.

Now, if we impose symmetry so that all importing firms who adjust their price at time t choose the same price, we may write the price index for imported goods facing the home country as the log approximation

$$p_t = (1 - \kappa)\tilde{p}_t + \kappa p_{t-1}. \quad (2)$$

Equations (1) and (2) together determine the degree of pass-through from exchange rates to prices. But since equation (1) gives the newly set price as a function not just of the current exchange rate but of the whole path of expected future exchange rates, it is clear that the relationship between s_t and p_t will depend on the time-series properties of s_t . Note that as $\kappa \rightarrow 0$, the law of one price holds, so that holding p_t^* constant, changes in exchange rates have one-for-one effects on the domestic price level.³

We may combine equations (1) and (2) to derive an inflation equation for imported goods prices,

$$\pi_t = \eta(\hat{\lambda} + q_t) + \beta E_t \pi_{t+1}, \quad (3)$$

where $\pi_t = p_t - p_{t-1}$ is the imported goods inflation rate, $q_t = s_t + p_t^* - p_t$ is defined as the real exchange rate, and $\eta = (1 - \beta\kappa)(1 - \kappa)/\kappa > 0$. This forward-looking inflation equation has been used in much previous work.⁴ Imported goods inflation will be higher when the real exchange rate is higher than its flexible-price equilibrium level, given by $-\hat{\lambda}$. The degree to which the real exchange rate can differ from the flexible-price fundamentals depends on the degree of price rigidity. As $\kappa \rightarrow 0$, the parameter η rises, and the deviation of the real exchange rate from the flexible-price fundamental falls.

3. We will show that, as $\kappa \rightarrow 0$, monetary policy continues to influence both prices and the nominal exchange rate, but proportionately, so that there is no net effect on pass-through.

4. As applied to exchange rate pass-through, see Devereux (2001) and Monacelli (2001).

2 Determination of the Exchange Rate

The previous section derived a relationship between the inflation rate in imported goods and the current and expected future exchange rate (equation (3)). We now derive a separate condition that will combine with equation (3) to jointly determine both the exchange rate and the inflation rate of imported goods. The underlying assumption behind the model is that the economy is so small and open that its total consumption basket consists of imported goods.⁵ Hence, the inflation rate of imported goods is the same as CPI inflation. Then, we may assume that the monetary rule used by the central bank takes the form

$$i_t = \phi + \delta \pi_t + u_t, \quad (4)$$

where i_t is the nominal interest rate, and the parameter δ captures the stance of monetary policy. Based on the principle of the Taylor rule, we assume that $\delta \geq 1$, so that the monetary authority follows a policy of increasing the ex post real interest rate in response to a rise in current inflation. A lower value for δ indicates a "looser" monetary policy. The parameter ϕ measures the target nominal interest rate set by the monetary rule. When $\phi > 0$, the authorities attempt to keep the interest rate systematically low. Finally, u_t is a random shock to the interest rate, representing uncertainty in the monetary rule. This could capture uncertainty about the type or preferences of the monetary authority.

The second condition that we use is the familiar relationship of uncovered-interest-rate parity (UIRP), given by

$$i_t = i_t^* + E_t s_{t+1} - s_t. \quad (5)$$

This will hold (up to a linear approximation) in any environment where asset-holders in the home economy have access to an internationally traded, foreign-currency-denominated bond.

Now, combining equations (4) and (5) gives

$$\phi + \delta \pi_t + u_t = r_t^* + E_t q_{t+1} - q_t + E_t \pi_{t+1}, \quad (6)$$

where $r_t^* = i_t^* - E_t(p_{t+1} - p_t)$ is the exogenous foreign real interest rate. Equation (6) implies equality between the nominal interest rate rule followed by the monetary authority, and the UIRP-determined nominal

5. In particular, there are no non-traded goods.

interest rate facing domestic agents. It gives a relationship between the inflation rate and the current and expected future real exchange rate.

Equations (3) and (6) form a simple dynamic system in domestic inflation and the real exchange rate. To solve these equations, we must be more specific about the shock processes. For the purposes of this paper, we focus exclusively on domestic monetary shocks.⁶ Assume that the monetary shock is governed by the following process:

$$u_t = \rho u_{t-1} + \varepsilon_t,$$

where $0 \leq \rho \leq 1$, and ε_t is an i.i.d., mean-zero disturbance. Using these assumptions, it is easy to establish that the solutions for inflation and the real exchange rate are as follows:

$$\pi_t = \frac{(r^* - \phi)}{(\delta - 1)} - a u_t, \quad (7)$$

$$q_t = \frac{(r^* - \phi)(1 - \beta)}{\eta(\delta - 1)} - \hat{\lambda} - b u_t, \quad (8)$$

$$\text{where } a = \frac{\eta}{[(\delta - \rho)\eta + (1 - \rho)(1 - \beta\rho)]},$$

$$\text{and } b = \frac{(1 - \beta\rho)}{[(\delta - \rho)\eta + (1 - \rho)(1 - \beta\rho)]}.$$

The intuitive interpretation of these conditions is as follows. If the monetary authority has a target for the nominal interest rate that is less than the steady-state foreign real interest rate, i.e., if $r - \phi > 0$, then steady-state inflation is positive. The steady-state real exchange rate is then determined by the steady-state inflation rate, and the steady-state price markup on imported goods. Note that the higher is the coefficient on inflation in the monetary rule, the smaller are both mean inflation and steady-state depreciation in the real exchange rate. Hence, for a given bias parameter, $r^* - \phi$, a "tighter" monetary policy (a higher δ) implies a lower mean inflation rate. While the monopoly markup $\hat{\lambda}$ affects the steady-state real exchange rate, it has no implications for the average inflation rate.

An expansionary money shock (which is equivalent to a fall in u_t) leads to a rise in inflation and a real exchange rate depreciation. The responses of both inflation and the real exchange rate are higher the more persistent the shock, but lower the higher the interest rate elasticity of the monetary rule.

6. In particular, we assume that the foreign real interest rate is constant.

Figure 1 illustrates some of the dynamic properties of the model's response to a money shock.⁷ Three parameters are important in the analysis. First, the monetary policy stance $\bar{\delta}$ affects the scale of the response of π and q , but it does not affect the *relative* response of the two variables. A tighter monetary rule (a higher $\bar{\delta}$) reduces the response of both inflation and the real exchange rate to a monetary shock, but the response of both variables falls by the same proportion.

As is to be expected, an increase in price stickiness (a fall in η) leads to a rise in the response of the real exchange rate and a fall in the response of inflation, since when prices are more sticky, it takes longer for the price level to adjust to a shock. Finally, a rise in the persistence of the shock (ρ) has two distinct effects. First, there is an increase in the size and persistence of the response of both inflation and the real exchange rate. But greater persistence also affects the *relative size* of the movement in q_t and π_t . A less persistent shock has a lower impact on domestic inflation, relative to the real exchange rate. As the shock gets more and more transitory, most of the response is confined to the real exchange rate. We will see below that this translates into a lower nominal exchange rate pass-through for more transitory shocks.

3 Exchange Rate Pass-Through

We now focus on the main issue of interest. How do nominal exchange rate changes pass through into changes in the domestic price level? In our framework, the failure of immediate pass-through can be solely ascribed to the presence of slow price adjustment. Since our focus is on domestic monetary policy shocks alone, if prices could adjust instantaneously, the real exchange rate would be constant, and the law of one price would hold continuously. The main objective of the investigation here is to isolate the structural determinants of low pass-through resulting from slow price adjustment.

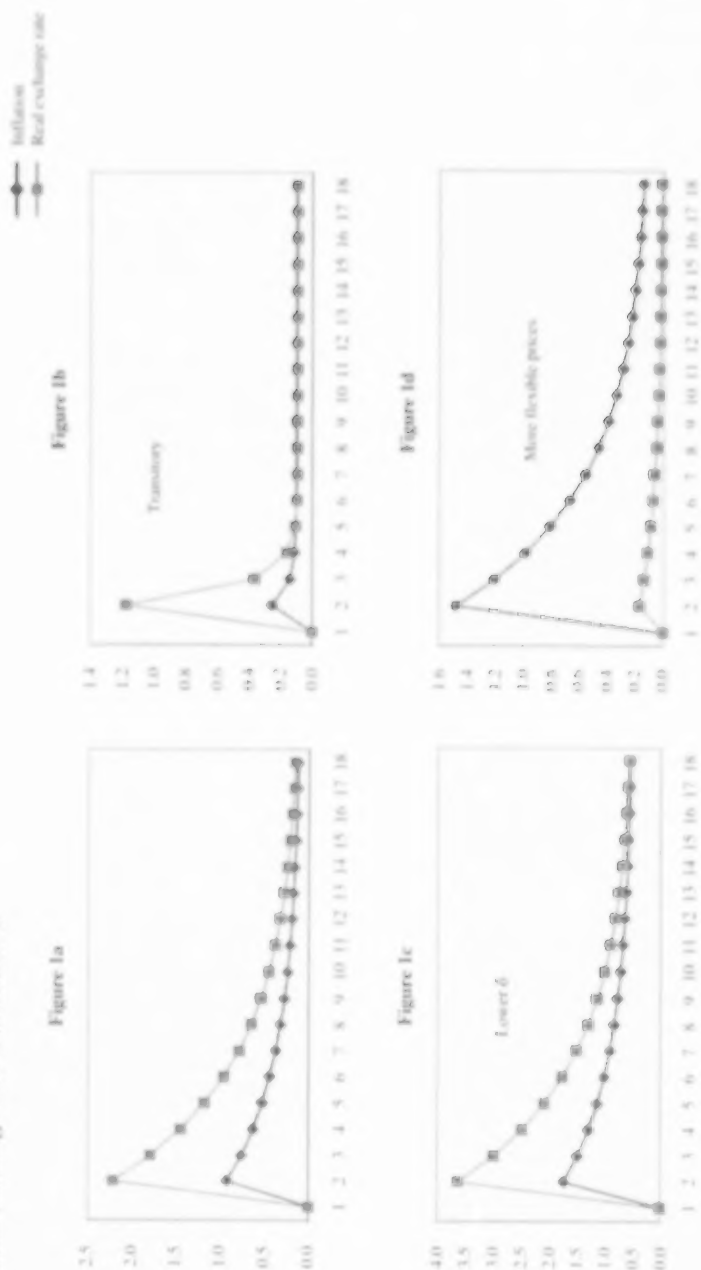
Pass-through is defined as a relationship between the nominal exchange rate and the domestic price level. From the inflation equation (6), we can write the domestic price level as

$$p_t = \frac{(r^* - \phi)}{(\bar{\delta} - 1)} - \alpha u_t + p_{t-1}.$$

Using this and the real exchange rate equation, we can determine the nominal exchange rate as

7. The parameter values used in the figure are outlined in section 4.

Figure 1
Real exchange rate and inflation



$$s_t = \frac{\phi}{(\delta - 1)} + (b + a)u_t - bu_{t-1} + s_{t-1}.$$

Shocks to both the nominal exchange rate and the price level are permanent, since both equations display a unit root. However, their short-run dynamics may be quite different in the face of slow price adjustment. We see that the exchange rate will always respond by more than the domestic price level in the short run, since such shocks cause an immediate real depreciation as well as domestic inflation. Thus, generically, short-run pass-through is incomplete in this economy. But, since the real exchange rate converges back to its equilibrium, the subsequent rise in the nominal exchange rate is slower than the rise in the price level.

Figure 2 describes the response of the nominal exchange rate and the price level following a monetary policy shock. Two parameters are critical in determining the response. For a more persistent shock, both the exchange rate and the price level tend to rise gradually over time, following the initial shock. But, for a transitory shock, the exchange rate tends to "overshoot," rising by more on impact than in the new steady state. The degree of price rigidity determines the extent to which movements in the exchange rate exceed the initial movements in the price level. Hence, we see that the implied pass-through of changes in the exchange rate to the domestic price level is highly sensitive to the persistence of the underlying shock, with transitory shocks having much less pass-through effect.

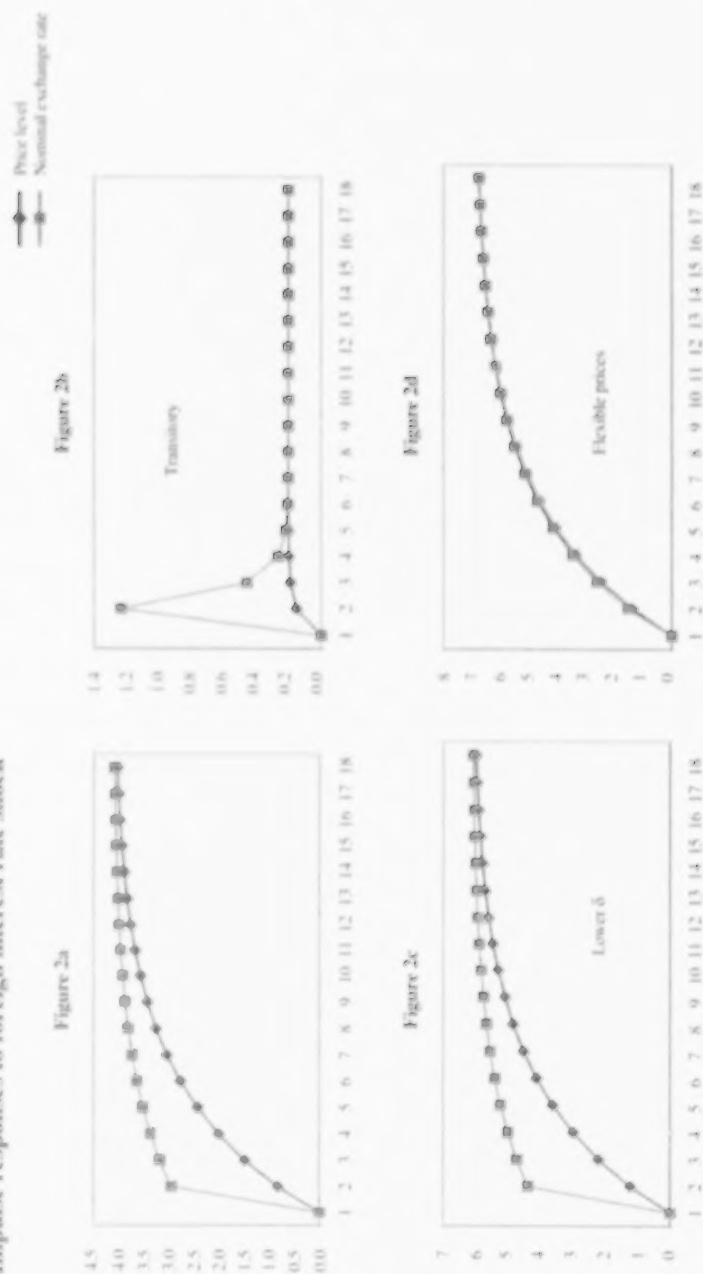
How does monetary policy affect pass-through? The answer is that, for given values of κ and given persistence, monetary policy has no effect. A tighter monetary policy (higher δ) reduces both the price and the exchange rate response to the shock, but the relative price to exchange rate response is unchanged. We may describe the immediate pass-through coefficient by the function

$$\frac{\text{cov}_{t-1}(s_t, p_t)}{\text{var}_{t-1}(s_t)}.$$

For interest rate shocks, this is equal to $a/(a+b) = \eta/(\eta + (1-\beta\rho))$. Therefore, for given η , this is independent of the monetary rule. However, as we will see, when we allow the frequency of price adjustment to be determined endogenously, the monetary rule may have a substantial impact on pass-through.

Table 1 describes the pass-through of a shock as a function of time, depending also on the persistence of the shock and the size of κ . For more persistent shocks, the immediate pass-through tends to be higher as inflation rises by more. But the subsequent degree of pass-through is quite small.

Figure 2
Impulse responses to foreign interest rate shock



On the other hand, for highly transitory shocks, the immediate pass-through is very low, but it quickly rises to unity, since the exchange rate falls as the price level rises.

Table 1
Exchange rate pass-through

	Baseline	Transitory	Low price rigidity
$t = 1$	0.28	0.12	0.89
$t = 2$	0.47	0.41	0.95
$t = 5$	0.76	0.98	0.99
$t = 10$	0.81	1.00	1.00

4 Endogenous Price Rigidity

So far we have assumed that κ is fixed exogenously. In studies of the effects of monetary policy on U.S. data, most researchers have assumed a constant degree of nominal price rigidity. In the calibration above, we set κ equal to 0.75, implying that the median price is adjusted after four quarters. But when we wish to compare pass-through estimates in cross-country data, it is unrealistic to assume a uniform value of κ . The underlying rationale for price rigidity is that firms incur some type of costs associated with price changes, either of the "menu-cost" or "contracting-cost" type (see Devereux and Yetman 2001). While these transactions costs are likely to be similar across countries, the benefits to firms from changing their prices may differ substantially. Moreover, they will differ in a systematic manner, depending on both the average inflation rate and the variability of the exchange rate. The higher the inflation rate, the more costly it is for a firm to set its price in terms of domestic currency and have its real return eroded by exchange rate depreciation. But the higher the inflation *variance*, the higher will be the expected losses from having prices preset for long periods of time. Finally, the higher the variance of the nominal exchange rate, the more variable the firm's "marginal cost" schedule, and the more the firm's price will depart from the efficient price, on average. Thus, we would anticipate that countries that have i) higher average inflation and higher volatility of inflation, and ii) higher variance of nominal exchange rates, will have lower κ , because the menu costs of price change would tend to be more than offset by the losses the firm incurs from keeping its price fixed in domestic currency. But since κ represents the key determinant of nominal exchange rate pass-through, we may conclude that the same two factors should contribute to a higher value of pass-through.

Furthermore, in our model, both the mean inflation rate and the volatility of the inflation and the exchange rate are related to the stance of monetary policy. For a higher value of δ , or a tighter monetary policy, the mean inflation rate is lower, and the variance of the exchange rate is lower. Hence, we would anticipate that countries that follow a more "conservative" monetary policy would tend to have lower exchange rate pass-through.

We may illustrate this point as follows. From this point on, to maintain tractability, we assume u_t shocks are i.i.d. Then we may write the process for the price level and the exchange rate as

$$p_t = \frac{(r^* - \phi)}{(\delta - 1)} - \frac{\eta}{\delta\eta + 1} u_t + p_{t-1}$$

$$s_t = \mu + \frac{(1 + \eta)u_t}{\delta\eta + 1} - \frac{u_{t-1}}{\delta\eta + 1} + s_{t-1},$$

where $\mu = \phi/(\delta - 1)$ is the average rate of exchange rate depreciation, which is decreasing in δ , as we noted before. The variance of inflation is

$$\sigma_\pi^2 = \left(\frac{\eta}{\delta\eta + 1} \right) \sigma_u^2,$$

and the variance of exchange rate changes is given by

$$\sigma_{\Delta s}^2 = \left[\left(\frac{(1 + \eta)}{\delta\eta + 1} \right)^2 + \frac{1}{(\delta\eta + 1)^2} \right] \sigma_u^2.$$

Both σ_π^2 and $\sigma_{\Delta s}^2$ are decreasing in δ . Hence, when we take the perspective that κ is endogenously determined on a country-by-country basis, we may anticipate that it will be systematically related to the monetary policy followed by each country.

We may illustrate the solution for the optimal κ for each firm. Ignoring the constant markup, the firm has a desired price each period given by the exchange rate

$$\hat{p}_{t+j}(i) = \begin{cases} s_t, & j = 0 \\ s_t + j\mu + \frac{(1 + \eta)u_{t+j}}{\delta\eta + 1} + \frac{\eta}{\delta\eta + 1} \sum_{i=1}^{j-1} u_{t+i} - \frac{u_t}{\delta\eta + 1}, & \forall j > 0 \end{cases}.$$

From equation (1), it is then straightforward to show that firms set prices according to

$$\tilde{p}_t(i) = s_t - \frac{\beta \kappa u_t}{\delta \eta + 1} + \frac{\beta \kappa \mu}{1 - \beta \kappa}.$$

The optimal value of κ then determines the probability that the firm's price will be constant at each period in the future. We assume that the firm must decide on κ in advance of price-setting for any period, so that κ minimizes $E_{t-1} L_t$. But since the environment is stationary, the firm will choose the same κ in each period. We may therefore think of the firm as choosing κ to minimize the stationary loss function,

$$L_t = \frac{(1 - \beta \kappa)}{(1 - \beta)} \left[F + E_{t-1} \sum_{j=0}^{\infty} (\beta \kappa)^j (\tilde{p}_t(i) - \hat{p}_{t+j}(i))^2 \right].$$

Substituting the expressions for $\tilde{p}_t(i)$ and $\hat{p}_{t+j}(i)$ into the stationary loss function, we obtain

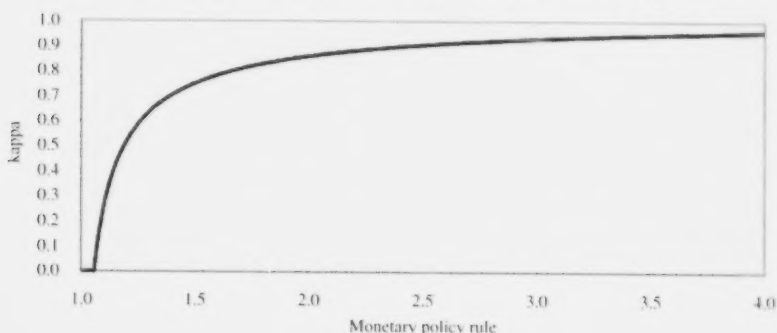
$$L_t = \frac{(1 - \beta \kappa)}{(1 - \beta)} \left[F + \frac{\beta \kappa \mu^2}{(1 - \beta \kappa)^3} + \frac{\beta \kappa \sigma_u^2}{(\delta \eta + 1)^2 (1 - \beta \kappa)^2} ((1 - \beta \kappa)(2(1 + \eta) - \beta \kappa) + \eta^2) \right].$$

The individual firm chooses its pricing frequency κ to minimize this stationary loss function, taking the κ 's of all other firms as given. This means that it takes the stochastic process for the exchange rate, and therefore the values of μ and η , as given, when choosing κ . A Nash equilibrium is defined as the value κ^N such that

$$\frac{\partial L}{\partial \kappa}(\kappa^N, \mu, \eta) = 0,$$

where $\mu = \mu(\kappa^N)$, $\eta = \eta(\kappa^N)$. The solution for κ^N is not, in general, analytical, but a simple numerical approach may be used. For this calculation, we use the following parameter values. The benchmark value of δ is set at 1.5, and the discount factor β is set at 0.95. If the benchmark value of κ is 0.75, this implies a value of η equal to 0.096. Setting ϕ equal to 0.015, steady-state inflation is 3 per cent. The standard deviation of the exchange rate (σ_{ds}) is taken to be 5 per cent, in the range of OECD exchange rate estimates, implying a variance of the shock of $\sigma_\epsilon^2 = 0.0015$. From equation (10), these parameter values, in turn, imply $F = 0.066$, so that changing price costs 6.6 per cent of steady-state profits. We then vary the δ parameter, which is equivalent to varying both the mean and variance of inflation, to investigate the dependence of κ on δ .

Figure 3 illustrates the dependence of κ^N on the monetary policy rule. As δ falls below 1.5, κ falls sharply. For δ below 1.06, price rigidity is

Figure 3**Probability of not adjusting price as a function of monetary policy**

completely eliminated, as all firms adjust prices each period. As δ rises above 1.5, κ rises, but flattens out quickly at values higher than 0.8. Note that the results can also be stated in terms of the average "contract length," or the average time between price adjustment, given by $1/(1 - \kappa)$. As δ falls, the average contract length falls, so when $\delta = 1.06$, adjustment takes place every period. But as δ rises, prices become fixed for increasing intervals.

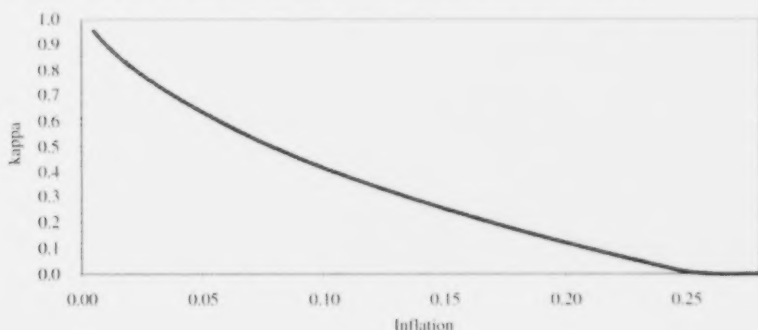
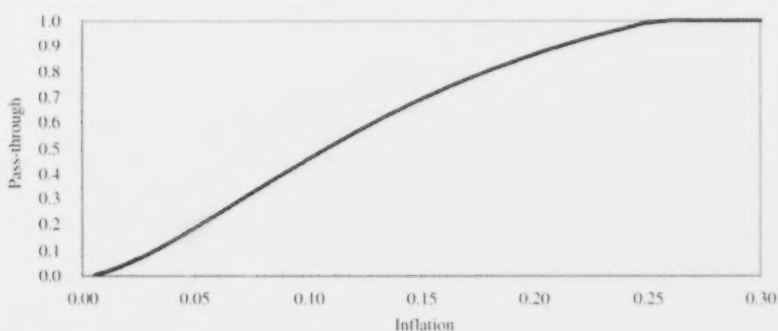
Figure 4 shows the relationship between κ and average inflation rates, given by $\phi/(\phi - 1)$. For the parameterization we use, as the inflation rate rises above 25 per cent, all prices become flexible.

Finally, Figure 5 gives the exchange rate pass-through estimates implied by the model as a function of the monetary policy rule.⁸ Consistent with the implications of the previous figures, we find that the short-run pass-through of exchange rates to prices is very low for our benchmark calibration—less than 10 per cent. But as inflation rises progressively, pass-through increases and is complete for inflation rates exceeding 25 per cent.

5 Empirical Implementation

While our theoretical model is too simple to be directly estimated, we may take a more indirect approach to testing the implications of the model. In a broad sense, our model points to the role of menu costs of price change in determining the speed with which changes in exchange rates pass through to domestic price levels. For countries with low inflation and low exchange rate

8. Pass-through in this special case is given by $\eta/(\eta + 1)$.

Figure 4**Probability of not adjusting price as a function of inflation****Figure 5****Exchange rate pass-through as a function of inflation**

volatility, we should anticipate pass-through to be quite low. In this case, in the presence of macro shocks that require adjustment of the real exchange rate, we should not expect to find any strong statistical relationship between changes in the exchange rate and changes in domestic price levels. But for countries with much higher inflation rates and higher exchange rate volatility, we'd expect to find higher exchange rate pass-through, as firms find that the menu costs of price change are more than offset by the loss from having prices far from their desired level. Moreover, this relationship should be non-linear: as inflation rises above some threshold, there should be no further impact of inflation on pass-through, since all prices are adjusted continually and pass-through is complete.

Our more fundamental hypothesis is that the rate of pass-through is ultimately related to the stance of monetary policy. Excessively loose monetary policy will imply a higher average rate of inflation and a higher level of exchange rate volatility.

We investigate the hypothesis by estimating a regression of the form

$$\Delta P_{ij} = \beta_{1j} \Delta S_{t-1j} + \beta_{2j} \Delta P_t^*,$$

where P_{ij} is the CPI of country j , S_{ij} is the U.S. dollar exchange rate of country j , and P_t^* is the U.S. CPI.⁹ Data are annual, to smooth out high-frequency fluctuations in the exchange rate, and they are taken from the IMF International Financial Statistics.¹⁰

Although this equation is not likely to represent a full specification for inflation determination, it should capture the aggregate influence of exchange rate movements on changes in national price levels.¹¹ For example, while both contemporaneous and lagged exchange rate changes may be expected to influence inflation, only lagged exchange rate changes are included in the regression to avoid any reverse endogeneity from domestic inflation rates to exchange rates biasing the estimates.

Our measure of exchange rate pass-through is the coefficient β_1 . The estimates of β_1 for the full sample (given in the Appendix) are quite sensible, in most cases lying between zero and one. Figures 6 and 7 contain scatter plots of the β_1 estimates against the mean inflation rate for each country. Figure 6 contains the estimates for all countries (excluding a few outliers), while Figure 7 contains only those countries for which β_1 was significant at the 5 per cent level.

We follow the methodology of Ball, Mankiw, and Romer (1988) in investigating a relationship between the estimates of exchange rate pass-through and trend inflation. The presence of menu costs suggests that exchange rate pass-through should be positively related to mean inflation, but with a non-linear relationship, since for inflation above a certain threshold, further increases in mean inflation should have no effect on pass-through. In addition, according to our model, exchange rate volatility should increase the measured rate of pass-through. Hence, we could run the regression

9. Similar results to those reported below are obtained if we include an intercept.

10. The IFS codes are ..RFZF... and 64..XZF... for the exchange rate and the inflation rate, respectively. All countries for which there are at least 10 annual observations in the post-Bretton Woods period (1970–2001) are included in the sample, with the exception of Hong Kong, for which there is virtually no nominal exchange rate volatility.

11. A similar approach is taken by Choudhri and Hakura (2001).

Figure 6
Pass-through (all countries)

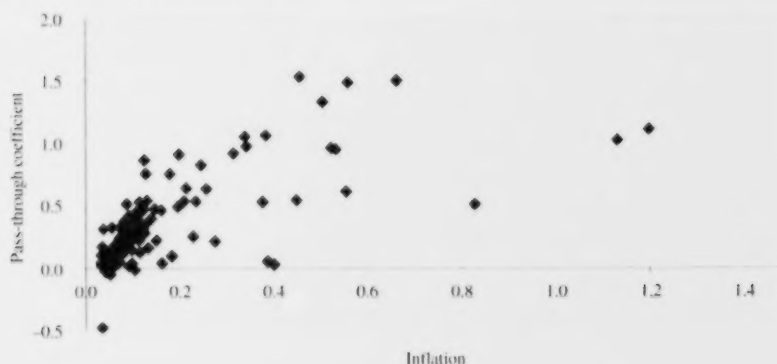
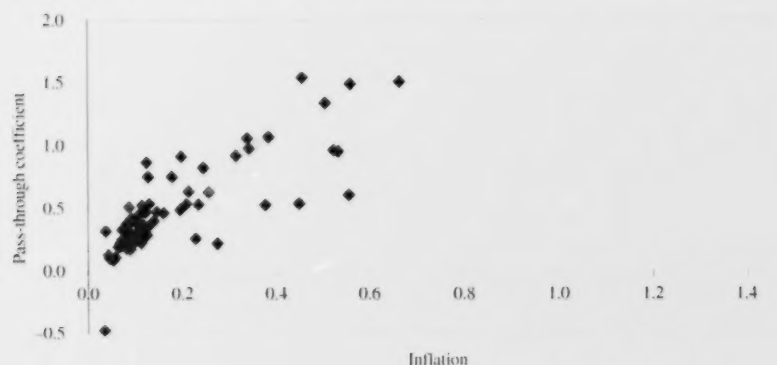


Figure 7
Pass-through (significant coefficients)



$$\hat{\beta}_{1j} = a_1\pi_j + a_2\pi_j^2 + a_3\text{var}(\Delta S_j),$$

where π is the mean inflation rate for country j and $\text{var}(\Delta S_j)$ is the variance of the exchange rate change vis-à-vis the U.S. dollar.¹²

In the model, firms should adjust their frequency of price change in response to changes in the mean rate of exchange rate depreciation. While the model

12. If an intercept is included, it is nearly always statistically insignificant, and the estimation results are virtually identical to those reported here.

implies that this is the same as the mean inflation rate, in reality, the two numbers may differ considerably. As an extra possibility, we estimate the equation adding on mean exchange rate depreciation and its square, as well as the standard deviation of domestic inflation, both separately and in combination.

Table 2 contains the results of all 122 countries in the sample. First, there is strong evidence that mean inflation tends to increase the rate of exchange rate pass-through,¹³ and that this effect dwindles as inflation rises. There is evidence of a similar effect for mean exchange rate depreciation. Inflation variance also has a positive and significant effect on the degree of pass-through, even when we control for the mean inflation and inflation squared. When we include *both* mean inflation and mean exchange rate depreciation as separate variables, as well as inflation variance, all variables are highly significant. In particular, there is clear evidence that both inflation and mean exchange rate depreciation separately increase the degree of pass-through, but in a non-linear fashion.

In the above results, the dependent variable includes estimated pass-through coefficients for all countries, including those that may be poorly identified. To confirm the robustness of the results, the estimation was repeated including only those 75 countries for which the estimated pass-through coefficient is significant at the 5 per cent level. The results are displayed in Table 3, and are very similar to those outlined in Table 2, clearly demonstrating the explanatory power of both the level and volatility of inflation and exchange rate depreciation for exchange rate pass-through.¹⁴

Separate estimates done on high-inflation and low-inflation countries (not reported) suggest that the influence of mean inflation and mean exchange rate depreciation on exchange rate pass-through is much weaker. But this is what we should anticipate, since, for countries with generally low (or high) rates of inflation, there should be little difference in pass-through. In general, the results support the hypothesis that sticky prices are an important factor in determining exchange rate pass-through at the aggregate level.

13. This is also shown in Choudhri and Hakura (2001).

14. While the coefficients on inflation and inflation volatility are highly robust to different formulations of the model, those on exchange rates and exchange rate volatility are less so. For example, including a constant in the first stage of the estimation, while statistically insignificant for the majority of countries, results in estimated coefficients on exchange rates and exchange rate volatility in the second stage of the estimation that frequently have the "wrong" sign. This anomaly can be explained by the high collinearity between the inflation and exchange rate variables (correlation coefficients of 0.83, 0.81, and 0.77 between the levels, levels squared, and standard deviations, respectively). Replacing each exchange rate variable with its component that is orthogonal to the comparable inflation variable completely eliminates the anomaly in this case.

Table 2
Dependent variable:
Estimated pass-through coefficient (all countries)

	(1)	(2)	(3)	(4)	(5)	(6)
Inflation	1.68*** (0.11)	1.19*** (0.07)	1.09*** (0.11)	1.54*** (0.19)	1.11*** (0.11)	1.20*** (0.12)
Inflation squared	-0.08*** (0.010)	-0.11*** (0.006)	-0.11*** (0.008)	-0.07*** (0.01)	-0.10*** (0.008)	-0.11*** (0.008)
Exchange rate depreciation				1.07 (0.83)	1.47*** (0.46)	2.41*** (0.71)
Exchange rate depreciation squared				-1.02 (1.27)	-2.46*** (0.71)	-3.29*** (0.85)
Standard deviation inflation		0.30*** (0.02)	0.30*** (0.02)		0.31*** (0.02)	0.31*** (0.02)
Standard deviation exchange rate			0.29 (0.23)			-0.60* (0.35)
R ²	0.85	0.95	0.95	0.86	0.96	0.96

Notes: Standard errors are given in parentheses; *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 3
Dependent variable:
Estimated pass-through coefficient (significant coefficients)

	(1)	(2)	(3)	(4)	(5)	(6)
Inflation	2.29*** (0.13)	1.45*** (0.14)	1.19*** (0.18)	3.42*** (0.19)	2.16*** (0.28)	2.16*** (0.28)
Inflation squared	-0.16*** (0.01)	-0.13*** (0.01)	-0.12*** (0.01)	-0.24*** (0.02)	-0.17*** (0.02)	-0.17*** (0.02)
Exchange rate depreciation				0.48 (0.61)	1.54*** (0.54)	1.68* (0.88)
Exchange rate depreciation squared				-8.02*** (0.97)	-5.72*** (0.91)	-5.79*** (1.00)
Standard deviation inflation		0.26*** (0.03)	0.26*** (0.03)		0.19*** (0.03)	0.19*** (0.04)
Standard deviation exchange rate			0.68** (0.32)			-0.09 (0.43)
R ²	0.88	0.94	0.94	0.95	0.96	0.96

Notes: Standard errors are given in parentheses; *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Conclusions

This paper makes two major arguments. First, the rate of pass-through from exchange rates to prices is at least partly determined by macroeconomic factors, in particular, sticky prices. Second, the rate of pass-through is sensitive to the monetary policy regime, precisely because the degree of price stickiness is endogenous to the monetary regime. The theoretical model shows how pass-through in a small open economy is determined by structural features of the economy, such as the persistence of shocks and the degree of price stickiness. When firms can adjust their frequency of price changes, we find that "looser" monetary policy leads to more frequent price changes and higher pass-through. Our empirical results provide strong support for the presence of price stickiness in determining the degree of pass-through. In particular, both mean inflation and mean exchange rate depreciation tend to increase pass-through, but in a non-linear fashion, as suggested by the model. For sufficiently high inflation rates (or mean exchange rate depreciation rates), price changes occur every period, and exchange rate pass-through is complete.

Overall, the evidence strongly points to the need to take into account the endogenous nature of exchange rate pass-through in designing monetary policy for a small open economy.

Appendix

Pass-Through Coefficients

Table A1

Country	Obs.	B ₁	Signif.	Country	Obs.	B ₁	Signif.
Algeria	29	0.47	0.000	Lebanon	24	1.33	0.002
Angola	11	5.86	0.029	Lesotho	24	0.30	0.002
Argentina	25	4.02	0.000	Luxembourg	28	0.12	0.002
Australia	31	0.10	0.177	Madagascar	31	0.47	0.000
Austria	28	0.03	0.339	Malawi	20	0.82	0.000
Bahrain, Kingdom of	11	-1.24	0.038	Malaysia	29	-0.03	0.669
Bangladesh	15	0.32	0.224	Maldives	12	0.42	0.138
Belgium	28	0.10	0.018	Mali	13	0.17	0.123
Bhutan	20	0.41	0.003	Malta	31	0.06	0.305
Bolivia	24	9.22	0.010	Mauritania	16	0.04	0.606
Botswana	27	0.27	0.000	Mauritius	31	0.04	0.684
Brazil	21	4.82	0.001	Mexico	26	1.05	0.000
Bulgaria	16	1.11	0.233	Morocco	31	0.18	0.002
Burkina Faso	18	0.11	0.199	Mozambique	13	0.03	0.848
Burundi	23	0.37	0.025	Myanmar	31	0.04	0.927
Cameroon	31	0.14	0.119	Namibia	21	0.22	0.001
Canada	31	-0.05	0.535	Nepal	27	0.51	0.000
Cape Verde	18	0.09	0.314	Netherlands	28	0.05	0.198
Central African Rep.	19	0.31	0.001	New Zealand	31	0.17	0.031
Chad	18	0.16	0.311	Nicaragua	18	7.14	0.005
Chile	30	1.50	0.000	Niger	31	0.16	0.130
China, P.R.: Mainland	13	0.19	0.335	Nigeria	29	0.25	0.044
Colombia	31	0.63	0.000	Norway	31	0.07	0.289
Congo, Dem. Rep. of	22	10.81	0.059	Pakistan	23	0.30	0.000
Congo, Republic of	15	0.13	0.397	Papua New Guinea	30	0.31	0.001
Costa Rica	26	0.75	0.000	Paraguay	17	0.46	0.000
Côte d'Ivoire	31	0.11	0.126	Peru	27	8.63	0.000
Cyprus	31	0.08	0.041	Philippines	31	0.46	0.001
Denmark	31	0.05	0.188	Poland	26	1.53	0.001
Dominican Republic	17	0.22	0.071	Portugal	28	0.36	0.000
Ecuador	21	0.92	0.000	Romania	11	1.02	0.074
Egypt	16	0.13	0.103	Rwanda	22	0.40	0.002
El Salvador	11	0.28	0.020	Samoa	31	0.24	0.027
Ethiopia	14	0.04	0.765	Saudi Arabia	17	-1.77	0.003
Fiji	31	0.05	0.618	Senegal	31	0.21	0.021
Finland	28	0.03	0.592	Seychelles	31	0.32	0.038
France	28	0.10	0.004	Sierra Leone	31	1.06	0.000
Gabon	30	0.22	0.036	Singapore	31	-0.48	0.006
Gambia, The	30	0.45	0.003	Slovenia	10	0.21	0.000
Germany	28	0.05	0.129	Solomon Islands	28	0.36	0.002
Ghana	25	0.05	0.736	South Africa	29	0.33	0.000
Greece	28	0.39	0.000	Spain	28	0.20	0.002
Guatemala	16	0.30	0.025	Sri Lanka	31	-0.01	0.922
Guinea-Bissau	14	0.52	0.035	Sudan	20	0.54	0.001

(continued)

Table A1 (continued)

Country	Obs.	B ₁	Signif.	Country	Obs.	B ₁	Signif.
Haiti	11	0.75	0.000	Swaziland	29	0.26	0.001
Honduras	12	0.52	0.000	Sweden	31	0.05	0.252
Hungary	29	0.96	0.000	Switzerland	31	0.02	0.601
Iceland	30	0.53	0.000	Tanzania	29	0.53	0.000
India	31	0.36	0.011	Thailand	27	0.03	0.702
Indonesia	26	0.16	0.075	Togo	31	0.19	0.049
Iran, Islamic Rep. of	28	0.09	0.054	Togo	26	0.37	0.008
Ireland	28	0.19	0.004	Trinidad and Tobago	19	0.14	0.064
Israel	31	1.48	0.000	Tunisia	18	-0.01	0.926
Italy	28	0.17	0.001	Turkey	30	0.96	0.000
Jamaica	26	0.48	0.001	Uganda	21	0.61	0.044
Japan	30	0.05	0.422	United Kingdom	31	0.11	0.080
Jordan	24	0.25	0.009	Uruguay	30	0.95	0.000
Kenya	29	0.53	0.000	Vanuatu	25	0.04	0.785
Korea	27	0.02	0.783	Venezuela	24	0.63	0.001
Kuwait	29	-0.03	0.842	Zambia	12	0.50	0.196
Lao People's Dem. Rep.	13	0.97	0.002	Zimbabwe	31	0.91	0.000

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Discussion

Jeannine Bailliu

Introduction

Devereux and Yetman investigate the role of sluggish price adjustment in explaining why exchange rate pass-through in the short run might be incomplete and why it might differ across countries. The paper is very topical, given the belief that pass-through has declined in many countries over the past decade and considering the debate over the role that monetary policy may have played in this decline. In the authors' framework, price rigidities can account for pass-through that is less than complete in the short run. Indeed, in their simple model of a small open economy, pass-through is determined by the frequency of price changes of importing firms. And this frequency is itself a function of the monetary policy regime and is, hence, endogenous. Thus, the variation in the *extent* of price sluggishness across countries—which arises because of differences in the monetary policy regime—can explain cross-country differences in short-run pass-through. The model's predictions are therefore consistent with Taylor's (2000) view that the decline in pass-through over the past decade is the result of the adoption of more credible monetary policy regimes.¹

My comments are organized as follows. First, I will examine the price-setting mechanism used in the model. Second, I will discuss local currency pricing, one of the model's key assumptions. I will then comment on the estimation results, and conclude by discussing what I view as some interesting policy implications of the paper for emerging-market countries.

1. Of course, we assume here that pass-through has, in fact, declined over the past decade, but this has yet to be firmly established in the literature.

Price-Setting Mechanism

In the model, price rigidities are the result of the presence of "menu costs" that firms must pay when they want to change their prices. The presence of these costs leads to the following objective function for the profit-maximizing firm, which the authors express as a loss function:

$$L_t = F + E_t \left[\sum_{j=0}^{\infty} (\beta \kappa)^j (\hat{p}_t(i) - \hat{p}_{t+j}(i))^2 + \frac{(1-\kappa)}{\kappa} \sum_{j=1}^{\infty} (\beta \kappa)^j L_{t+j} \right].$$

The loss function has three elements. The first, F , is defined as the share of average profits that goes to price adjustment. The second element is the expected discounted value of losses resulting from the difference between the new price and the desired one. The third element is the expected value of the loss function that applies when the firm changes its price again in the future. My understanding is that the second and third terms represent Calvo-type rigidities where adjustment costs are implicit. But note that this has been shown in the literature to be equivalent—in the sense that one can obtain the same pricing equations—to using explicit quadratic adjustment costs (see, for example, Rotemberg 1982). It is unclear to me, therefore, why in addition to having Calvo-type rigidities as expressed in the last two terms, there is the extra term, F , representing the explicit cost of price adjustment. It would have been useful to see a discussion of whether it is possible to model price rigidities without this additional term and, if so, what the implications are of including this term. For instance, does it introduce additional rigidity?

Local Currency Pricing

In the paper, all firms set their prices in the local currency, even though the importing firms face their costs in terms of the foreign currency (these firms do not use any domestic inputs, including labour). The assumption of local currency pricing (LCP) is not used consistently across the literature, so it is important to emphasize that, in this paper, this assumption encompasses much more than simply the currency denomination of the country's imports: it is also a form of pricing to market. Consequently, it is one of the model's key assumptions, and its importance can be illustrated by considering the case of assuming the opposite assumption, foreign currency pricing (FCP). In this case, pass-through would be both immediate and complete.

Accordingly, a consideration of FCP would not be particularly constructive. However, it might be worth examining an intermediate case, where some firms set their prices in the local currency, while others set them in the

foreign currency. A combination of these two pricing assumptions might be more realistic as an economy-wide characterization, since evidence suggests that the degree of pricing to market varies by industry. In addition, the assumption that all importing firms in the economy follow LCP might appear a little extreme in a model of a small open economy. It is unclear to me how modifying this assumption would influence the model's predictions. I suspect that it might mitigate some of the results, but not overturn them.

Estimation Results

The authors test the implications of their model by first estimating a simple pass-through equation for every country in their sample, and then regressing the estimated pass-through coefficients on a series of explanatory variables that are shown to be a function of the monetary policy regime in their model. In the individual country estimations, the pass-through coefficient for some of the countries is larger than one and statistically significant. There are 11 such countries, all of which are developing or transition economies.² It is not clear to me whether such a result is consistent with the model. It might therefore be useful to discuss whether there is a restriction in the model that pass-through be less than 100 per cent or whether pass-through can exceed its long-run threshold in the short run.

If this sort of result is consistent with the theoretical definition of pass-through, an elaboration of this scenario might be useful. For instance, does the model offer any insights about what is driving pass-through over 100 per cent? Can it be traced back to a particular type of shock? Most of the countries with pass-through greater than 100 per cent experienced periods of high inflation over the sample period and, in some cases, hyperinflation. Therefore, it is most likely that high inflation fed into inflation expectations, creating an inflation spiral. This spiral was typically instigated by factors other than the exchange rate (e.g., in many of these countries, the governments ran large budget deficits and attempted to finance them by printing money). However, one would still observe a high degree of correlation between the rate of depreciation of the nominal exchange rate and inflation, because higher inflation would lead to a depreciation in the exchange rate. It is not surprising, therefore, that one would find a high rate of estimated pass-through in these countries, even if the exchange rate had not instigated the cycle.

2. These countries are: Angola, Argentina, Bolivia, Brazil, Democratic Republic of Congo, Lebanon, Mexico, Nicaragua, Peru, Poland, and Sierra Leone.

Concluding Remarks

In closing, I would like to discuss the potential policy implications of this paper for emerging markets. In my view, the paper has very interesting and relevant policy implications for emerging markets that have, over the past decade, significantly reduced their inflation rates and adopted more credible monetary policy regimes. For instance, many of these countries in Latin America, such as Mexico, Brazil, and Peru, have brought inflation down significantly in the 1990s and have recently adopted floating exchange rate regimes coupled with inflation targeting. These new regimes are generally perceived as being more credible than previous ones. It is believed that pass-through has declined in these countries as a result, although this belief is based largely on anecdotal evidence or event studies, since there are not yet enough data points to conduct an econometric study. In the context of an inflation-targeting regime, it is obviously very important for policy-makers to understand what has happened to pass-through with the adoption of the new monetary policy regime. This model can provide a theoretical explanation for why one might expect pass-through to have declined in this situation. Indeed, the model would suggest that as inflation fell in these emerging markets, price stickiness would have increased, and pass-through would have declined.

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Discussion

Beverly Lapham

This is an interesting paper that explores a link between monetary policy, inflation, and exchange rate pass-through to consumer prices. The issues raised are important, because the relationship between nominal exchange rate fluctuations and consumer price movements has implications for monetary policy and exchange rate policy. In particular, if the association between nominal exchange rates and consumer prices is weak, the expenditure-shifting effects of monetary shocks are diminished. Furthermore, the classic case for exchange rate flexibility attributed to Friedman (1953) and Feldstein (1997) depends crucially on nominal exchange rate movements being passed through to consumer prices. They argue that exchange rates must be able to respond to shocks so as to generate relative price adjustments necessary for stabilizing the effects of those shocks on output. If, however, consumer prices are unresponsive to exchange rate fluctuations, this relative price adjustment will not occur, and these automatic stabilizing arguments for flexible exchange rates are no longer valid.

Devereux (2001), Devereux and Engel (2002, 2001), Engel (2000), and others make this point and examine optimal exchange rate policy in theoretical models with no immediate pass-through. Also, a better understanding of the connection between exchange rates and consumer prices provides insight into the factors that influence price determination. For example, it will allow us to better determine the relative importance of microeconomic factors such as market structure and macroeconomic factors such as inflation on the price-setting behaviour of manufacturers and retailers.

In this paper, Devereux and Yetman develop a model with nominal rigidities. This model provides a link between monetary policy and the

degree of exchange rate pass-through. The intuition behind this link is straightforward. Firms optimally choose how often to change prices in response to exogenous shocks. In making this choice, they consider the fixed cost associated with a price change and the losses associated with not changing their prices in times of inflation (which causes real prices to fall) and in response to nominal exchange rate movements (which affect their costs). Thus, tighter monetary policy, which lowers inflation, leads to smaller losses from holding prices constant and, therefore, is associated with lower degrees of pass-through. This is a significant contribution to the theoretical literature, since it provides an explicit connection between monetary policy and exchange rate pass-through in a tractable model with nominal rigidities.¹

The authors also provide empirical pass-through estimates for U.S. dollar exchange rates for a large set of countries using standard methods. They then use the country cross-sectional feature of their data to examine the relationship between inflation rates and their pass-through estimates. The results indicate a positive relationship between the level of inflation and the degree of pass-through.

These empirical findings are broadly consistent with evidence given by Choudhri and Hakura (2001), Gagnon and Ihrig (2001), and other cross-sectional studies. Related time-series evidence suggests that the relationship between exchange rate movements and core CPI in Canada weakened considerably in the relatively lower inflationary period of the 1990s (see, for example, Bank of Canada (2000)). Other authors, such as Campa and Goldberg (2002), Laflèche (1996–97), Goldfajn and Werlang (2000), and McCarthy (2000) have explored inflation and other determinants of pass-through such as the composition of imports. In addition, there is a large literature that explores the importance of market structure and industrial organization considerations for pass-through, and much of this work is surveyed by Goldberg and Knetter (1997). Kardasz and Stollery (2001) focus on Canadian industries in a recent example of this approach.

What is apparent from the literature is that the relationship between exchange rates and prices is complicated and the factors affecting the price-setting behaviour of retailers are varied and complex. With this in mind, I visited a number of local retailers in Kingston [Ontario] and inquired about their business with a focus on their price-setting decisions. My conversations with the owner of a long-established independent shoe store were particularly interesting. It became clear that many factors come into play

1. See, Taylor (2000) who examines links between monetary policy and pass-through of cost changes to prices.

when he sets his prices. Shoe prices in other markets such as Toronto and New York appeared to be important, as did the suggested retail price from the manufacturer. The retailer further emphasized that the nature of competition in the retail shoe industry had changed because of the exit of Canadian manufacturers and independent shoe retailers and the entry of chain stores. I was also left with the impression that the cost of changing his retail prices was not a significant component in his decision-making. My conversations with these retailers convinced me that the relationship between retailers, wholesalers, and manufacturers is complex, that it may have changed in recent years, and that "optimal" price-setting by these retailers is a complicated exercise.

I turn now to outstanding issues raised by this paper and related papers surrounding the relationship between exchange rates and the prices of goods. One issue concerns the stability of the relationship. In this paper, the relationship is stable but is a function of macroeconomic variables such as the inflation rate. It would be useful, however, to explore the possibility that changes in market structure, contract duration, energy prices, technology, and so on have caused a fundamental shift in the relationship. Closely related is the importance of sorting out the relative significance of microeconomic versus macroeconomic factors that affect these relationships.

This paper's reliance on nominal rigidities in retail prices to generate low degrees of pass-through raises questions regarding the evidence on stickiness in retail prices. Bills and Klenow (2002) present data on the duration of consumer prices for a large set of goods. Their findings indicate frequent price changes with half of the prices in their sample lasting less than four months. These findings are important, especially since many of the measures of pass-through (including those in Devereux and Yetman) analyze annual data. Perhaps other sources of stickiness, such as wage stickiness and contracts between retailers and manufacturers, are important for explaining low levels of pass-through.

Nonetheless, it is difficult to deny the growing evidence suggesting a positive relationship between inflation rates and pass-through rates. Consequently, we might ask whether there is an alternative story that is consistent with this evidence that does not rely on retail price rigidities. A promising avenue is based on models of consumer search developed by Benabou (1988, 1992) and Diamond (1993). Head and Kumar (2002) explore such a model to examine the relationship between inflation and the dispersion of consumer prices. In their environment, an increase in inflation has two effects on real prices. First, it raises consumers' reservation prices, thereby increasing real prices. Second, it leads to more price dispersion,

increases the search intensity of consumers, and lowers real prices. When average inflation is low, the second effect dominates and, thus, monetary shocks are not fully passed through to nominal prices. In contrast, when average inflation is high, the first effect dominates and nominal prices rise by more than the money supply. Therefore, in this model, inflation and pass-through of monetary shocks are positively related. An interesting difference between this approach and the model of Devereux and Yetman is that in the latter, inflation reduces price dispersion, whereas in this environment, inflation increases price dispersion.

This paper, the related literature, conversations with retailers, and these outstanding issues have directed my thoughts to possible directions for future research. It is essential that researchers give increased attention to the microeconomic details surrounding exchange rate pass-through. A better understanding of price-setting behaviour will allow us to develop better measures of exchange rate pass-through that control for other factors affecting prices. We must also have measures of pass-through at higher levels of industry disaggregation and at various stages of production and distribution. We require a deeper understanding of relationships between manufacturers, importers, wholesalers, and retailers and insight into how those relationships may have changed. In exploring the link between policy and pass-through, we should consider the possibility that industries respond to shocks and changes in policy along margins of adjustment other than price movements. For example, entry and exit and industry restructuring in response to shocks may alter the relationship between exchange rates and prices.

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General Discussion*

Michael Devereux thanked the discussants and offered the following comments regarding:

- **the value-added of the first model relative to the second:** the model works nicely and is therefore interesting to open-economy macroeconomists.
- **calibration:** it could be refined, but given the model's simplicity, calibration is not very important, the simplification being that firm prices were assumed not to be functions of the state variables.
- **other determinants of pass-through:** they were significant but both microeconomic and macroeconomic approaches were possible. The macroeconomic side is important to look at because of the high inflation, high pass-through relationship.
- **the presence of the term F in the price-setting mechanism:** while it was not needed in the Calvo case, it was necessary in this model; otherwise, the frequency of price adjustment would be infinity.
- **local-currency pricing:** if there were none, there would be no need to consider infrequent price adjustments. Devereux acknowledged, however, that it would be beneficial to have an intermediate case analysis where local and foreign-currency pricing are considered. This, however, was not feasible in the paper.

* Prepared by Marwan Chacra and Maral Kichian.

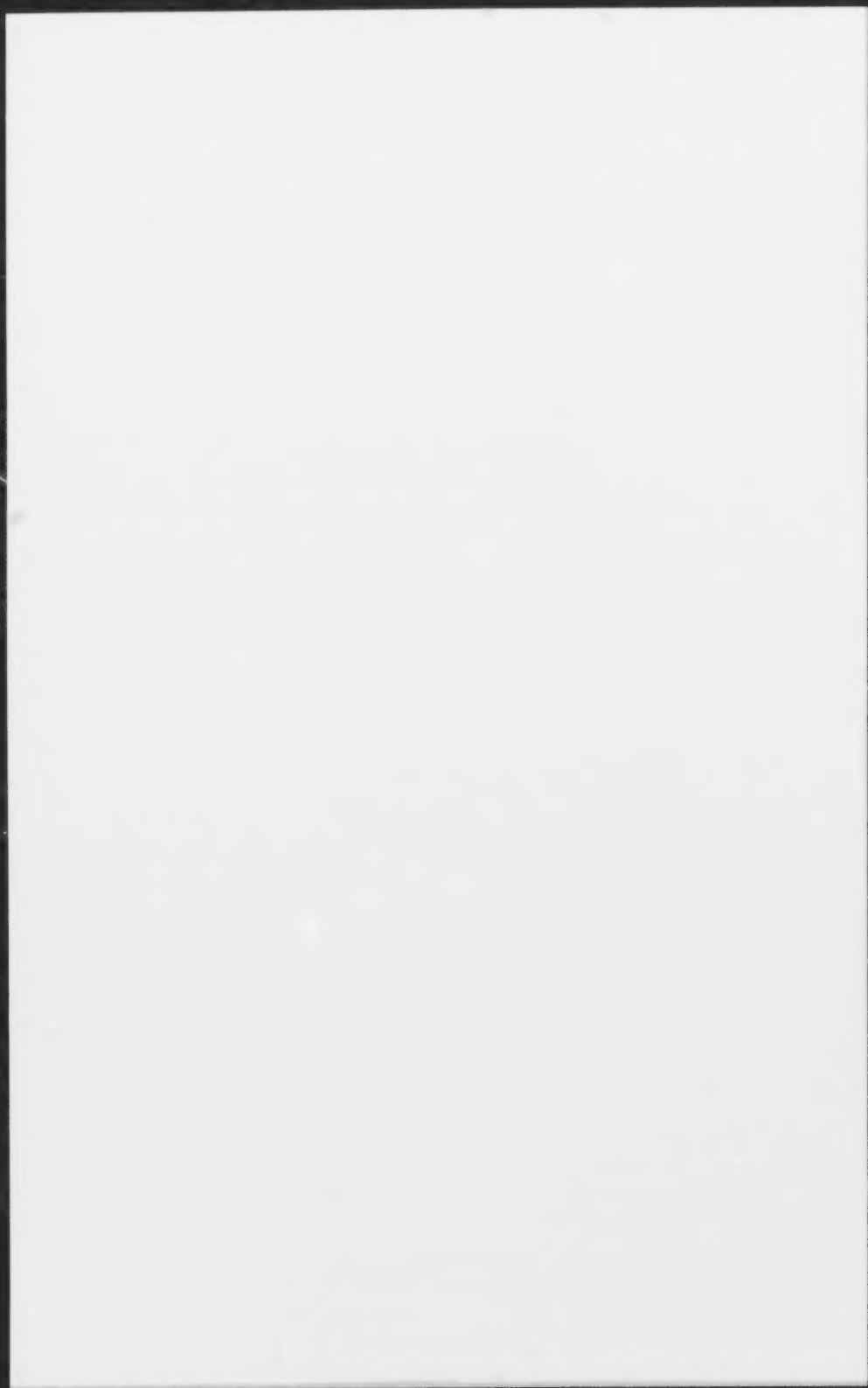
- **the pass-through coefficient > 1 :** it occurs because there are many different shocks in the model, and because the exchange rate jumps a lot with transitory shocks. He added that their estimates were rough and that there was no need to control for other things, such as GDP per capita (which they had tried).

Regarding the reaction function, Nicholas Rowe felt that the interest rate is a function of inflation but not of the exchange rate. Thus, the model reveals what happens to pass-through if the central bank allows for it. But, in reality, the central bank does not allow for it.

Devereux agreed with Rowe and added that δ increases as the central bank's reaction to inflation increases, and that the pass-through tends to zero.



Panel Discussion



Discussion 1

Gregor Smith

In these comments, I shall explore a number of common themes that emerged from the conference papers. My fellow rapporteurs are experts in monetary theory and monetary policy, and so I shall focus on some of the econometric questions raised by the papers. These papers are the work of skilled econometricians; consequently, my comments are intended to suggest further research directions.

Identification

At the outset of the conference, we knew (at least) two things about inflation:

- (i) It is difficult to forecast. This finding is well known to researchers who fit output gaps or Phillips curves. Whether the difficulty in forecasting inflation is due to an absence of severe shocks, poor statistical specification, or good policy, is less clear.
- (ii) Theories of inflation often involve variables that are not directly observable. Examples include measures of the output gap or of marginal costs. Our uncertainty about these measures carries over to uncertainty about what drives changes in the inflation rate.

The empirical conference papers all contribute to our knowledge of price adjustment. But the process of reading them "en masse" revealed a number of pitfalls in statistical identification that may warrant further study.

First, because of inflation targeting, it might be difficult to identify any Phillips curve during the 1990s. Rowe and Yetman (2002) argue that successful inflation targeting should result in changes in the rate of inflation that are unpredictable. Under inflation targeting, there is little variation in actual inflation, and so it is difficult to identify Phillips curves. This policy

environment may thus explain some of the challenges encountered by Kozicki and Tinsley and Guay, Luger, and Zhu in their impressive papers.

Second, using first-order conditions from price-setting rules may not be enough to identify their parameters. Call π_t the inflation rate and use y_t to refer to the output gap or a measure of marginal cost. The New Keynesian Phillips curve is then:

$$\pi_t = \beta E_t \pi_{t+1} + \alpha \pi_{t-1} + \gamma y_t.$$

Kozicki-Tinsley's equation (1) or Guay-Luger-Zhu's equation (9) are of this general form.

Gregory, Pagan, and Smith (1993) show that when y_t follows a random walk, β will not be identified by using instrumental variables methods. An unidentified model can be estimated, but the estimators will be inconsistent and will have a non-standard statistical distribution. A similar problem may afflict Guay-Luger-Zhu's equation (14), since it used no additional identifying information other than the difference equation. If y_t does not follow a random walk and is still persistent, β may be only weakly identified.

Stock and Wright (2000) have provided some econometric tools for GMM estimation when identification is weak. But an appealing alternative is to use information on the process followed by y_t , whether it is marginal cost or an output gap. Michel Normandin and Jean Boivin both suggest something like this in their comments. This approach requires more statistical modelling, but it may ensure that the forward-looking part of the Phillips curve is identified. Moreover, it will add to the efficiency of the estimates.

A third example of an identification problem can be illustrated with an even simpler, traditional Phillips curve:

$$\pi_t = \gamma_t y_t + \varepsilon_t,$$

and let us imagine that the slope varies over time like this:

$$\gamma_t = \gamma - \lambda \pi_t.$$

The idea is to explore the possibility that, as inflation fell from the 1980s to the 1990s, the Phillips curve became flatter. Several of the conference papers suggest that such a shift has occurred in Canada over time, in that the Bank of Canada's improved credibility led to an improved trade-off between inflation and unemployment. Combining the two equations gives:

$$\pi_t = \gamma y_t - [\lambda \pi_t y_t - \varepsilon_t].$$

This combination looks like a Phillips curve with a constant slope but a composite error term (in brackets) with time-varying volatility that might even mimic ARCH. It is well known that time-varying parameters can be observationally equivalent to residual heteroscedasticity.

In this example, when inflation falls, credibility rises, and the duration of contracts may rise too. In our ersatz Phillips curve, conditional volatility will fall as well, and will be correlated with the rise in duration. Thus, this example suggests that the papers on the conditional mean of inflation (Kozicki-Tinsley and Guay-Luger-Zhu) might be related to studies that focus on the volatility of inflation (Fay-Lavoie). Moreover, this evolving credibility and contract duration may explain why it is difficult to identify a Phillips curve with stable coefficients. In this case, parameter stability tests might be informative. In some cases, however, learning from single-equation methods may be too much to ask.

Information

A second theme from the empirical work of the conference is that aggregates may not provide enough information to answer many of our questions about price adjustment.

The Fay-Lavoie study is an excellent example of combining information sources from a survey. It would be valuable to have even more information on the contracts they study. Do those firms and workers take into account the durations of contracts signed recently? Is information available on the pricing decisions of those firms, so that the real-wage costs of the firm can be tracked? What are the details of COLA clauses?

While Fay and Lavoie carefully study several measures of inflation uncertainty, another measure might be that implied by derivative prices in the fixed-income market. Using this information could add to the precision of their findings.

My guess is that industry models or models with a strategic element may be useful in characterizing price adjustment. Drawing from the perspective of various price-adjustment schemes, such as those in the Kozicki-Tinsley paper, Davis and Hamilton (2002) study wholesale gasoline prices set by dealers. They find that none of the standard price-adjustment rules describes that data well and conclude that price-setting is a game of strategy between the dealers.

Using industry models to study pricing requires that attention be paid to the cross-sectional dimension of data. Researchers at the Bank of Canada

certainly have skills in working with panel data and these skills may well become increasingly valuable in macroeconomic research.

On the subject of pass-through, some additional sources of information might be worth exploring. Time-series evidence on the persistence of exchange rate changes could be combined with the Devereux-Yetman approach, because this persistence may affect the scale of pass-through and may vary across countries. A second way of adding information to pass-through studies is to focus on the prices of specific goods (rather than CPIs) and to control for shocks to exporters' costs. Goldberg and Knetter (1997) outline this approach.

In studying pass-through, Devereux and Yetman monitor how prices change in response to changes in the nominal exchange rate. I would suppose that information on the levels of the exchange rate and prices might also be useful in future studies along these lines. For example, suppose that the price of a specific good is lower in Canada than in the United States, quoted in a common currency. Consider a compact disc that costs US\$15 in the United States and Can\$20 in Canada. Say that the exchange rate is 65 cents (US) so that the Canadian CD price, quoted in U.S. dollars, is US\$13.

Next, suppose that the Canadian dollar appreciates in nominal terms, to 68 cents (US). If one is studying aggregate pass-through using changes, one might expect Canadian prices in general to fall, towards Can\$19.11 if the pass-through coefficient were unity. A smaller drop in the Canadian price would be seen as evidence of incomplete pass-through. But if one also had information on the levels, this partial response could be viewed as evidence that prices are converging in the two countries over time (since the initial Canadian price is below the U.S. price), in keeping with an integrated goods market.

Moments

Much of the empirical work in the conference papers is presented in terms of statistical moments. Although these are natural and general ways to begin comparing models with data, some of the models do so well that further information—from sample paths—seems useful. For example, an interesting question suggested by the Fay-Lavoie paper is that there is a cycle in contract duration that would appear to merit further study. Most importantly, in the Kozicki-Tinsley paper, it would be intriguing to discover whether the sample path of inflation is explained largely by the series of inflation expectations or by the output gap. To what extent is the flat path of inflation in the 1990s the result of the series of shocks, and to what extent is it the result of policy responding to shocks or anchoring expectations?

Bowman and Doyle's excellent review of the new open-economy macroeconomics shows how it has focused on moments and on matching impulse-response functions from monetary shocks. Given the speed of progress in this field, one would expect that these models will soon yield sample paths. Bowman and Doyle also describe how the preoccupation in the new open-economy macroeconomics has been with producing realistic price and exchange rate movements in response to exogenous monetary shocks. Again, one would expect that these models will soon include other shocks, with monetary policy in part responding to them. Scott Hendry made a similar observation in his comments on the Alexopoulos paper.

Policy Effectiveness

The effectiveness of monetary policy emerges as a common theme in many of the statistical results. Fay and Lavoie conclude that contract duration has increased as inflation uncertainty has fallen. Kozicki and Tinsley find that the credibility of inflation targets appears to have increased during the 1990s. Their best-fitting Phillips curve is also quite flat. The best-fitting model in the Alexopoulos paper features partial employment insurance. In that model, a monetary policy shock produces relatively large changes in output, employment, and investment, with little response in inflation. Moreover, these results do not require an unrealistically large wage elasticity of labour supply. In a similar vein, the studies by Devereux and Yetman and by Bowman and Doyle document the surprisingly low pass-through of exchange rate changes into domestic prices. Again, this stickiness is consistent with monetary policy shocks having large real effects.

The good news is that all of these findings remind us that inflation targeting is consistent with stabilization policy—provided that there is some kind of Phillips curve—and that monetary policy certainly has real effects. The bad news is that relatively small deviations from an inflation target may be associated with relatively large movements in real activity, if the short-run Phillips curve has become flatter over time. This environment seems to demand great vigilance from policy-makers.

I will conclude on an optimistic note about research on price adjustment. It is clear from these thought-provoking conference papers that developments in applied econometrics and in general-equilibrium modelling are converging. At a Bank of Canada conference in the near future, we shall see a range of general-equilibrium models that allow welfare analysis and the calculation of optimal policies, and that also fit many key features of the time series from economic history.

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Discussion 2

Michael Woodford

Finding an empirically realistic model of pricing dynamics is of crucial importance for the conduct of monetary policy. One reason is obvious: central banks cannot be expected to maintain a reliable and stable macroeconomic environment if their deliberations are not guided by an accurate conception of the effects of their actions. But the questions addressed at this conference are significant for other reasons as well. For example, the way in which prices are set has important consequences for the central bank's stabilization objectives if it wishes to maximize social welfare. Price stability matters for welfare because of the way prices are adjusted in response to changing conditions. In the textbook world of perfectly flexible wages and prices, maintaining stable purchasing power of the unit of account would be of little significance. It then follows as well that the sense in which it is desirable for inflation to be stabilized will depend on how inflation dynamics are related to real distortions.

As we shall see, the nature of inflation dynamics matters for several aspects of the optimal conduct of monetary policy. First, alternative pricing models can lead to different views of the optimal long-run inflation target. Second, they can imply different perspectives of the optimal dynamic responses of inflation to disturbances, and hence to different views of the degree to which temporary departures from the long-run target should be allowed. And finally, alternative models can change the form of the targeting rule to which a central bank should commit itself to bring about those optimal responses to disturbances, while guaranteeing the desired long-run average rate of inflation. These aspects demonstrate that the way prices are set should affect the nature of a central bank's policy objectives and commitments, and not simply the actions that it must take to fulfill those commitments.

I shall illustrate these points in a simple example drawn from recent debates on the correct empirical specification of the aggregate-supply relationship. To do so, I shall compare specifications that differ in the degree of inflation inertia that they imply. A straightforward way of incorporating inertia into the dynamics of inflation has been proposed by Christiano, Eichenbaum, and Evans (2001) and used in the empirical models of Smets and Wouters (2002), Altig et al. (2002), Boivin and Giannoni (2003), Sbordone (2003), and Giannoni and Woodford (2003). In this extension of the standard Calvo model of staggered pricing, prices do not remain fixed between the random occasions on which they are reoptimized. The log price of a good i in period t can be expressed as

$$p_t(i) = v_t(i) + \gamma P_{t-1},$$

where $v_t(i)$ is a good-specific base price, and the coefficient $0 \leq \gamma \leq 1$ indicates the degree of indexation of prices to the (lagged) general price index P_{t-1} . The base price remains fixed between the random occasions on which it is reoptimized; thus, in periods when no reconsideration of the base price occurs, the price of good i increases by fraction γ of the lagged overall rate of inflation. (The lag is presumably attributed to lags in the availability of data on the aggregate price index.) The base price is reset at random intervals to the level that maximizes expected discounted profits at that time.

As shown in Woodford (2003, chapter 3), this leads to an aggregate-supply relationship of the form

$$\pi_t - \gamma \pi_{t-1} = \kappa x_t + \beta E_t(\pi_{t+1} - \gamma \pi_t) + u_t, \quad (1)$$

where π_t is the inflation rate (change in the price index P_t), x_t is an output-gap measure, $0 < \beta < 1$ is the discount factor, the coefficient $0 < \kappa < 1$ depends on both the frequency with which prices are re-optimized and the degree of real rigidity, and u_t is an exogenous cost-push shock. Note that when $\gamma = 0$, this reduces to the familiar New Keynesian Phillips curve considered in several papers at this conference. Furthermore, the inertial specification that results when $\gamma = 0$ is closely related to the hybrid model of Gali and Gertler (1999), also considered in extensive recent empirical literature, though the microeconomic foundations proposed by these authors are slightly different. Finally, in the limiting case that $\gamma = 1$, equation (1) is essentially the form of aggregate-supply relationship proposed by Fuhrer and Moore (1995), on the basis of different micro-foundations and fit to U.S. data in a number of studies.

When we consider the goals of monetary stabilization policy, what are the consequences of the estimated value of γ , which indicates the importance of lagged inflation as a determinant of current inflation? Woodford (2003,

chapter 6) shows that in a model with staggered pricing of the kind just described, maximization of the expected utility of the representative household is equivalent (up to a quadratic approximation) to minimization of the expected discounted value of a loss function of the form

$$L_t = (\pi_t - \gamma\pi_{t-1})^2 + \lambda_x(x_t - x^*)^2, \quad (2)$$

if one abstracts from monetary frictions, where $\lambda_x > 0$, $x^* > 0$ are functions of model parameters.

Thus, the appropriate stabilization objective with regard to inflation is not stabilization of the rate of inflation, but rather of $\pi_t - \gamma\pi_{t-1}$. The reason is simple: in this model, inflation results in real distortions owing to the fact that the prices of different goods are not adjusted in a perfectly synchronized fashion, and this results in price misalignments. The distortion is minimized by a current inflation rate equal to $\gamma\pi_{t-1}$, which is the rate of automatic increases in the prices that are not reoptimized in period t . Inflation occurs at this rate when conditions are such that reoptimizing firms choose a rate of price increase equal to $\gamma\pi_{t-1}$, the rate at which their prices would have increased had they not reoptimized, and this is the case in which the fact that some firms reoptimize while others do not does not increase the misalignment of prices. Note in the Fuhrer-Moore case that it is only the rate of inflation *acceleration* that matters for welfare, and not the absolute rate of inflation at all (abstracting from monetary frictions).

If the model is extended to allow for monetary frictions (and hence a positive demand for base money despite its being dominated in rate of return), the appropriate welfare-theoretic loss function (2) takes the more general form

$$L_t = (\pi_t - \gamma\pi_{t-1})^2 + \lambda_x(x_t - x^*)^2 + \lambda_i(i_t - i^m)^2, \quad (3)$$

where $\lambda_i > 0$ depends on the size of the monetary frictions, and i^m is the interest rate (if any) paid on base money. When $\lambda_i > 0$, the absolute rate of inflation is relevant to welfare even when $\gamma = 1$, since the long-run average nominal interest rate will depend on the long-run average rate of inflation. Suppose, for example, that interest rates are related to inflation and real activity through the log-linear Euler equation

$$x_t = E_t x_{t+1} - \sigma(i_t - E_t \pi_{t+1} - r_t^n) \quad (4)$$

of the basic neo-Wicksellian model presented in Woodford (2003, chapter 4), where $\sigma > 0$ represents the intertemporal elasticity of substitution, and r_t^n is the (exogenously varying) natural rate of interest. The long-run

average rates of interest and inflation must therefore satisfy the Fisher relationship

$$E[i] = \bar{r} + E[\pi],$$

where $\bar{r} \equiv -\log \beta > 0$ is the long-run average value of the natural rate of interest.

I now turn from the appropriate loss function, describing the objectives of monetary policy, to the characterization of the optimal equilibrium paths of inflation and other variables. The first concern relates to the optimal long-run inflation target. Let us consider the problem of choosing a path for the inflation rate, under commitment, from some date t_0 onward in the case where there are no random disturbances ($u_t = 0$, $r_t^m = \bar{r}$ at all times). This amounts to choosing a sequence $\{\pi_t\}$ to minimize the discounted sum of losses (equation 3), if the associated paths of the output gap and the interest rate are determined by equations (1) and (4). One can show that the optimal sequence converges asymptotically to a constant long-run inflation target $\bar{\pi}$. To a first-order approximation (adequate in the case of small enough disturbances), this is also the long-run average value of inflation under an optimal state-contingent commitment in the presence of random disturbances.

In the case of standard Calvo pricing ($\gamma = 0$), the optimal long-run inflation target is given by

$$\bar{\pi} = -\frac{\lambda_f}{\lambda_f + \beta}(\bar{r} - i^m), \quad (5)$$

as shown in Woodford (2003, chapter 7). Note that in the flexible-price limit ($\lambda_f \rightarrow \infty$),¹

this reduces to

$$\bar{\pi} = -(\bar{r} - i^m) < 0, \quad (6)$$

which is the usual Friedman rule: bring about a rate of deflation where the interest rate differential between the monetary base and other riskless short-term nominal assets is eliminated. Instead, in the "cashless" limit of an economy with negligible monetary frictions $\lambda_f \rightarrow 0$, the optimal inflation target reduces to

1. In the case of flexible prices, the direct distortions associated with inflation disappear. Because I have normalized the π_t^2 term in equation (3) with a coefficient of 1, this corresponds to infinitely large values for λ_i and λ_{π} .

$$\bar{\pi} = 0.$$

When monetary frictions and sticky prices coexist (the case of finite positive λ_j), the optimal inflation target lies between these extremes.²

When we allow for inflation inertia ($\gamma > 0$), matters are more complex. The optimal inflation target is given by

$$\bar{\pi} = -\frac{\lambda_j}{\lambda_j + \beta(1-\gamma)(1-\beta\gamma)}(\bar{r} - i^m),$$

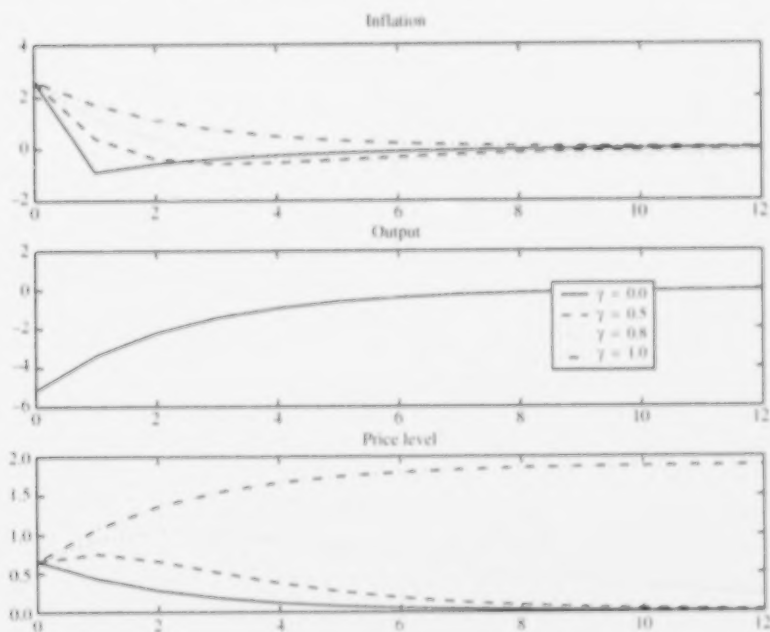
generalizing equation (5). Note that a larger γ means a lower optimal inflation target. Indeed, in the limiting case that $\gamma = 1$, the Friedman rule (equation 6) is optimal regardless of the size of λ_j . As noted above, the reason is that distortions resulting from imperfect synchronization of price changes depend on the rate of inflation acceleration, and not on the absolute rate of inflation. Any constant long-run inflation rate is therefore equally good from that point of view, and it is only the minimization of the distortions associated with a positive opportunity cost of holding money that matters in the determination of $\bar{\pi}$.

One's belief about the empirically realistic value of γ also has important consequences for the optimal responses to random shocks. Consider the optimal response to a transitory, unforecastable cost-push shock u_j , under an optimal state-contingent commitment. In the case of a small enough shock, the optimal responses (per unit unexpected in u_j at the date corresponding to zero on the horizontal axis in the figure) of inflation, output, and the price level are of the form shown in Figure 1. See Woodford (2003, chapter 7) for further discussion of the kind of calculations involved in this figure. For the sake of simplicity, I abstract from monetary frictions, and the numerical results assume calibrated parameter values $\beta = 0.99$, $\kappa = 0.024$, as described in detail in the book manuscript.

The optimal dynamic response to such a disturbance depends in important ways on the value of γ . When $\gamma = 0$ (standard Calvo pricing), it is optimal to immediately begin to undo the price increase resulting from such a shock as soon as the effects of the shock on the aggregate-supply relationship have dissipated (see analysis in Clarida, Gali, and Gertler 1999). The commitment to do so restrains price increases in the period of the shock, and as a result allows a reduction in the distortions resulting from inflation in that period without requiring a severe contraction of output relative to its

2. I have abstracted from a variety of reasons for the desirability of a slightly positive inflation target, such as measurement bias in the price index or downward nominal-wage rigidity.

Figure 1
Optimal responses to a positive cost-push shock under commitment,
for alternative degrees of inflation inertia



natural rate. If, instead, γ is substantially positive, it is optimal to allow prices to continue to increase, albeit at a slower rate, for a time following the shock, even though it is still optimal to commit to an eventual period in which the inflation rate will undershoot its long-run target value, so that the price level eventually returns to the path that would have been expected in the absence of the shock. In the limiting case that $\gamma = 1$, the period of undershooting never occurs under an optimal commitment; instead, inflation is only gradually reduced to its long-run target value, and the price level remains permanently higher.³ Results with some of the same flavour are also

3. It is worth noting, however, that inflation does not remain permanently higher as a result of such a disturbance under an optimal commitment. It might be thought that our conclusion above—that only the rate of acceleration of inflation matters for welfare when $\gamma = 1$ —would imply that cost-push disturbances should be allowed to permanently affect the rate of inflation as long as inflation is expected to stabilize again at *some* rate. But this is not true under the optimal state-contingent commitment, even when we abstract from monetary frictions. Allowing for monetary frictions provides another reason for the long-run average inflation rate not to be changed by a temporary disturbance.

obtained by Steinsson (2002) in the context of a model with backward-looking rule-of-thumb price-setters similar to the model of Gali and Gertler 1999.

Thus far, I have considered the consequences of the value of γ for the nature of the equilibrium path of inflation that one should seek to bring about through monetary policy. One can also consider the consequences of this parameter estimate for the form of an optimal policy rule to which a central bank might commit itself to achieve an equilibrium of the kind just characterized. A particularly appealing way in which to specify such a policy is to use a target criterion as part of a forecast targeting procedure. This is a policy rule under which the central bank is committed to use its policy instrument in whatever way is needed to ensure that the projected evolution of the economy continues to satisfy the target criterion. As discussed in Woodford (2003, chapter 8), one important aspect of this way of specifying the policy rule is that a characterization of optimal policy can be given in these terms that is robust to alternative specifications of disturbance processes.

As shown in Giannoni and Woodford (2003), the optimal target criterion takes a simple form in the cashless limit of the model discussed above; the central bank should ensure that in each period,

$$\pi_t - \gamma \pi_{t-1} + \frac{\lambda_x}{K} (x_t - x_{t-1}) = 0. \quad (7)$$

Remember that in this case, the optimal long-run inflation target is given by $\bar{\pi} = 0$. This indicates that a short-run departure of the projected inflation rate from the long-run target should be acceptable to the extent that it (i) reflects automatic inflation as a result of the indexation of non-yet-reoptimized prices to the lagged price index; or (ii) is offset by a projected change in the output gap. Note that (as long as $\gamma < 1$) neither factor would justify a projected *permanent* departure from the long-run inflation target (here equal to zero). The amount of inflation in the future that can be justified as a result of inflation that has already occurred should fall to zero as one looks far enough ahead, and changes in the output gap should similarly not be projected to continue indefinitely. The value of γ matters for the formulation of the target criterion and not simply in determining what the feasible inflation/output trade-offs should be at various future horizons. A larger γ justifies a larger weight on recent past inflation in the calculation of the acceptable short-run inflation projection (or alternatively, a slower projected rate of return to the long-run inflation target).

Consequently, we see that a judgment of the value of γ should have important consequences for the characterization of optimal policy in several

respects. Which of the cases examined here should be considered as a basis for policy deliberations? Recent empirical literature tends to favour specifications with large values of γ . Several authors have even argued for the realism of assuming full indexation ($\gamma = 1$). The papers presented at this conference have also tended to support the view that lagged inflation is an important determinant of current inflation, and that this effect should be considered structural, as in the model outlined above with $\gamma > 0$.

Some important questions remain, however, before we can be comfortable making policy on the basis of the conclusions regarding the character of optimal policy when γ is large. These questions represent important caveats to the conclusions that I have just described. But they are also reasons to question whether the current empirical literature can answer the questions about the nature of price-setting that must be settled in order to reach firm conclusions about optimal policy.

Many of the studies that argue for the importance of inflation inertia use data from the 1960s through the 1980s, when policy in both the United States and Canada allowed inflation to drift without an apparent anchor for quite some time. (Axel Leijonhufvud once characterized this regime as a "random-walk monetary standard.") But should we really expect inflation inertia to continue to characterize price-setting behaviour to the same extent in an environment of more credible commitment to an inflation target? Even if a model of staggered pricing with a large value of γ accurately describes pricing dynamics in the period just mentioned, it is not clear that such indexation to lagged prices is immutable, rather than something that might well change under an alternative policy commitment—indeed, as something that may well be changing already, given the policy changes in the two countries over the past 15 years. After all, it hardly makes sense to think that indexation to a lagged price index should be an institutional necessity, as opposed to an adaptation to particular conditions.

Moreover, it is not clear that the evidence offered in favour of the hypothesis of indexation price to actual past inflation could not be equally well explained by indexation of prices to past expectations regarding the current rate of inflation. This is particularly so in the period from 1965 to 1985, when there was substantial serial correlation in inflation, and past expectations of current inflation would reasonably have been highly correlated with the past rate of inflation. While a large number of recent empirical studies have estimated the degree of inflation inertia under the assumption that it is the actual past rate of inflation that should affect current inflation with a greater or lesser coefficient, none have sought to distinguish the effect of actual past inflation from past inflation expectations.

But these alternative interpretations of the evidence for inflation inertia would have significantly different consequences for the character of optimal policy. For example, if one supposes that there has recently been considerable backward-looking indexation, but that it would disappear in an environment of consistently low and stable inflation (or deflation), then one might argue that it would be more reasonable to commit to a monetary policy rule that leads to optimal outcomes in a world without indexation, given that such a commitment should lead to an abandonment of indexation. On the other hand, commitment to an optimal rule for an economy with large γ would be self-defeating, since it would tend to bring about an end to the conditions under which the rule had been expected to be optimal.

Similarly, if one assumes that prices are automatically indexed between occasions of reoptimization, but that the indexation is to past expectations of inflation (perhaps averaged over several prior quarters), one should not expect large distortions to result from a policy of committing to a rapid return of inflation to its normal level (or even to undershoot it) following a cost-push shock. When an increase in inflation associated with such disturbances is not expected to persist, such an increase should not have much effect on the automatic component of inflation in subsequent quarters. Thus, it might be optimal to commit to return inflation to its normal level much more rapidly than the simulations in Figure 1 would indicate in the case of a high value of γ .

Determining which of these interpretations is more realistic should be a topic for further empirical research on inflation dynamics. More theoretical analysis of the way in which alternative specifications matter for the conclusions that one would draw about optimal policy will also help, by clarifying which differences between the specifications are of greatest practical significance.

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Discussion 3

Pierre Duguay

Introduction

First, let me thank Bill Scarth for his tribute to our dear friend and colleague John Kuszcak. I also want to thank all of you, and especially the presenters, the discussants, and my fellow panellists, for making this conference a success.

The occasion has given us a unique opportunity to take stock of the current state of knowledge on important interactions between economic decisions and monetary policy. I will review the presentations and discussions in the context of the following questions, with an emphasis on the implications for monetary policy and further research.

1. What is the best way to represent empirically the price-adjustment process?
2. What do small open-economy models say about price adjustment and/or monetary policy?
3. What are the implications of a technology shock?
4. How has sustained low inflation affected labour market behaviour?

1 What is the best way to represent empirically the price-adjustment process?

As Bowman and Doyle wisely observe, monetary policy remains an empirical endeavour. It thus seems appropriate to begin with the papers on empirical models of price adjustment.

The papers by **Kozicki** and **Tinsley** and by **Guay, Luger**, and **Zhu** address issues that strike at the core of our preoccupations as central bankers. We are grappling with conceptual and empirical issues around the appropriate measure of the output gap—needed in real time, as pointed out by Simon van Norden, the representation of expectations, the unscrambling of intrinsic from expectational dynamics, and the choice of an inflation measure. In addition, we would like to identify the implications of regime changes, including changes in the degree of credibility of monetary policy, for the dynamics of inflation. I was thus keenly interested in reading the empirical papers and in hearing the discussion on them. I have learned a great deal and will offer some observations in return.

Guay, Luger, and **Zhu** test the ability of a New Keynesian Phillips curve specification to explain the behaviour of inflation in Canada. That specification relates inflation to real marginal costs rather than to the output gap. If we accept the assumption that real marginal costs are proportional to the labour share of output, that gives the specification a distinct advantage over the more traditional Phillips curve. It can rely on observed data rather than on judgmental estimates of the unobserved output gap. Unfortunately, the New Keynesian Phillips curve model is found not to provide a good representation of inflation dynamics for Canada.¹

That result did not surprise me. The New Keynesian pricing model focuses on the adjustment of prices from the point of view of a firm that takes wage costs as given. It is missing the core Phillips relationship between demand pressure and wage growth. Given the procyclical nature of profits, I find it hard to think of the labour share as an adequate proxy for excess demand.

I would also question the appropriateness of the New Keynesian pricing specification for a small open economy like Canada, where a significant proportion of prices (commodities and automotive products, for example) are set in world markets rather than by Canadian producers. Indeed, fluctuations in the Canadian GDP deflator largely reflect externally driven movements in the terms of trade. I would therefore suggest that, at a minimum, it is the terms of trade or real commodity prices, rather than real import prices or the real exchange rate, that should be used to augment the New Keynesian pricing equation when explaining the Canadian GDP deflator. Alternatively, the New Keynesian pricing equation could be used to explain final demand rather than domestic value-added deflators, with real marginal costs expanded to include the cost of intermediate inputs such as imports. The point is that while one would expect the broad trend of

1. André Kurmann (2002) raised serious doubts about the ability of the model to track inflation behaviour in the United States.

inflation to be reflected in most aggregate price indexes, there can be significant differences in short-run movements of different indexes.

Kozicki and Tinsley conclude that inflation dynamics are better captured by models with both leads and lags of inflation—a position that we adopted for the Bank's projection model—and possibly leads and lags of the output gap as well. While I strongly subscribe to David Laidler's empirical observation that "unemployment and output changes seem to precede the price and wage changes associated with them" (Laidler 1982, 129), I can easily conceive of price-setting depending on expected future demand and not only on the current or past output gap, particularly in the case of non-perishable goods and services.

That would help explain why the Phillips curve appears to have flattened under inflation targeting (Dupasquier and Ricketts 1998). The flattening cannot be explained merely by the fact that inflation expectations are better anchored. But when we consider that inflation control acts also as an economic stabilizer, we begin to see how a given output gap may put less pressure (up or down) on inflation if it is expected to be short-lived.

But the key message from Kozicki and Tinsley is the importance of paying attention to shifts in the nominal anchor when modelling the behaviour of inflation. And their major, original result is their interpretation of the low persistence of inflation in the 1990s as evidence of increased credibility for the low-inflation target in Canada. You will not be surprised that I find this interpretation appealing. But beyond that, it accords quite well with survey evidence and qualitative information, and it helps explain what Pierre Fortin refers to as the mystery of the missing deflation. With the announcement of the target renewal in May 2001, we have tried to consolidate our gains on this front by extending the target horizon, by focusing on the 2 per cent midpoint of the target range, and by committing to explain any sustained deviation of actual inflation from the midpoint.

2 What do small open-economy models say about price adjustment and/or monetary policy?

Bowman and Doyle survey the literature on New-Keynesian, open-economy models. Their survey received high praise from the discussants and participants and will serve as a benchmark for years to come. I found their discussion on the implications of producer currency pricing (PCP) and local currency pricing (LCP) particularly interesting. As it turns out, the extent of PCP versus LCP is a key issue for the formulation of monetary policy.

The authors show that with PCP, typically assumed by default, monetary policy should aim to stabilize domestic production prices and allow the consumer price level to move with the real exchange rate. They qualify this result somewhat by noting that where the real balance effect is important, the literature suggests that the authorities should incorporate CPI inflation into the targeting process.

Bowman and Doyle also note that extensive LCP implies more variability of the nominal exchange rate, because larger changes are needed to affect the relative prices of imports. But I wonder whether the smaller response of import and export demand might not be partly offset by a larger supply response.

In Canada, we know that a significant proportion of our producers (I mentioned car and commodity producers) are price-takers in world markets. There is also strong evidence of LCP of some imports. Earlier this year, Bank of Canada staff conducted an Internet survey of the prices of 55 consumer products (of which 25 were different car models) in Canada and the United States. The price quotes were drawn from affiliated companies or comparable large stores, they excluded taxes and transport costs, and they pertained to rigorously identical products in both countries. We found strong evidence of LCP for some products—automobile, furniture, compact discs, for example, but not for others.

It would appear that our situation in Canada could be described by the incomplete pass-through literature. My reading of Bowman and Doyle would be that the CPI is thus the appropriate target for monetary policy. This is an important insight. At one point, we were considering whether we should not pay more attention to a measure of trend inflation that excluded the estimated direct pass-through effect of exchange rate movements on prices in formulating monetary policy, as suggested by Ball (1999). The difficulty of obtaining precise estimates of what appeared to be a vanishing pass-through held us back.

Devereux and Yetman suggest that this vanishing of the exchange rate pass-through may, in fact, be an endogenous outcome of low-inflation policy. They show how low and stable inflation may imply less frequent price changes and lower exchange rate pass-through than higher and more variable inflation. And they present cross-country evidence to support their hypothesis. Like the discussants, I have reservations about the econometrics, given that the estimating regression is not a complete model of price determination. However, I find the argument intuitively appealing and consistent with the stylized facts. For instance, we have observed a clear reduction in the exchange rate pass-through in the 1990s in Canada and many other countries. And we know that inflation underwent a widespread

decline from the 1970s and 1980s to the 1990s. This leads me to ponder whether we might not gain greater insights by splitting the sample period around 1991-92. This would allow us to compare for a given country the change in the estimated pass-through coefficient between a high- and a low-inflation environment.

Gabriel Srouf uses the rigorous setting of New Keynesian models to re-examine the conventional wisdom on the role of monetary policy in a small open economy producing goods whose prices are set on the world market. The most interesting question he addresses is the implications of the degree of cross-sector labour mobility for monetary policy. In a country as large and regionally diverse as Canada, this is a perpetual issue. One thing is clear: monetary policy can be controversial. Without labour mobility, monetary policy is always too tight for some regions or industries, and too loose for others. However, as Craig Burnside points out, the model may be too stark. It would be more helpful to examine the case of imperfect labour mobility, allowing for adjustment costs, than the two extremes of complete mobility or immobility. While complete immobility will definitely thwart the ability of monetary policy to replicate the flexible-price equilibrium, it does not follow that complete mobility is required to achieve that goal.

3 What are the implications of a technology shock?

What happens after a permanent technology shock? In light of the technology boom-bust cycle that recently sent a shock wave across the world economy, the answer given by **Christiano, Eichenbaum, and Vigfusson**—that hours worked rise monotonically rather than first falling—does seem rather unspectacular. But a follow-up answer ignited a fascinating debate that brought the very identification of technology shocks to the front door of the central bank! As Tiff Macklem commented, technology shocks are found to matter little for the real economy but a lot for inflation. And if monetary policy gets it wrong, it can create considerable havoc in the real economy.

I must say that I am puzzled by the finding that under unchanged money growth, a positive technology shock should produce initial declines in output and employment. I would have thought that under sticky nominal wages, unchanged nominal spending could accommodate the higher output resulting from a positive technology shock through lower prices with unchanged employment. And since a positive technology shock would increase investment, it would also tend to raise interest rates and lower money demand. Thus, a constant money-growth rule might, in fact, accommodate some increase in nominal spending. Whether that would be enough to accommodate the possible increase in labour supply brought

about by higher real wages, or whether some hard-to-come-by contraction in wage growth might still be needed to equilibrate demand and supply for labour, remains an open question. But I would not have expected employment to fall under the circumstances.

I am also curious about the estimated reaction function of the Fed that produces the accommodative policy. I find it difficult to believe that the Fed that has kept inflation under 3 per cent in the last seven or eight years is using the same rule as the Fed that allowed inflation to get into the double digits in the 1970s and 1980s. In fact, allowing for a regime shift may help resolve some of the thorny identification questions that were raised during the discussion.

Michelle Alexopoulos considers a positive technology shock in her limited-participation model with an embedded efficiency wage model. She finds the responses to be qualitatively consistent, although not quantitatively identical, with the predictions of the standard limited-participation model—output, real wages, employment, investment, and interest rates all rise, and the price level decreases. Her objective is to replicate the conjunction of low real wage variation and high employment variation observed in the U.S. data without having to rely on unrealistically large elasticity of labour supply. Her imaginative answer is to enrich the model with the notions of shirking, pay-at-risk, unemployment, and risk-sharing arrangements. From the perspective of a monetary policy maker, this is a welcome leap for a dynamic general-equilibrium model. Although, as pointed out by the discussant and a number of participants, it would be instructive to incorporate other frictions. As an aside, I should correct the misconception that lump-sum cash injections from the central bank are a source of profit for the banking system. Seigniorage from money creation actually goes to the government.

The model does not seem to fit the Canadian data. A glance at Canadian and U.S. real wage and employment data tells the story (Figure 1). It reveals much larger co-movements between real wage and employment in the United States than in Canada. This suggests that technology shocks may have been more dominant in the United States and demand shocks more dominant in Canada.

4 How has sustained low inflation affected labour market behaviour?

Howitt (1997) and others have noted that low, stable inflation should facilitate long-term plans and commitments. **Fay** and **Lavoie** ask whether reduced inflation uncertainty can be shown to have played a role in the lengthening of labour contracts in the inflation target period. In doing so,

Figure 1**Real (consumer) wage growth and employment growth**

Year-over-year percentage change

Canada



United States



they are careful to account for both real and inflation uncertainty and to make a distinction between uncertainty and variability: not all variability is uncertain. Their results corroborate previous studies in finding that low inflation uncertainty (usually associated with sustained low inflation) leads to longer wage contracts and hence lower bargaining costs overall, and thus, in turn, helps make inflation more stable.

Some participants expressed unease at the finding that real and inflation uncertainty had different effects on the length of labour contracts—namely, real uncertainty had none. I believe there could be a simple explanation for this. Real shocks tend to affect different sectors in different ways, requiring greater idiosyncratic adjustments in real product wages, output, and employment across sectors than in relative wages (see Baldwin, Durand, and Hosein (2001) for empirical evidence on this). Therefore, real shocks should not require renegotiation of labour contracts. But inflation shocks would, because they would disturb relative wages. This asymmetry of real and inflation uncertainty on the length of labour contract is reminiscent of the asymmetry of optimal indexation to real and nominal shocks (Gray 1976).

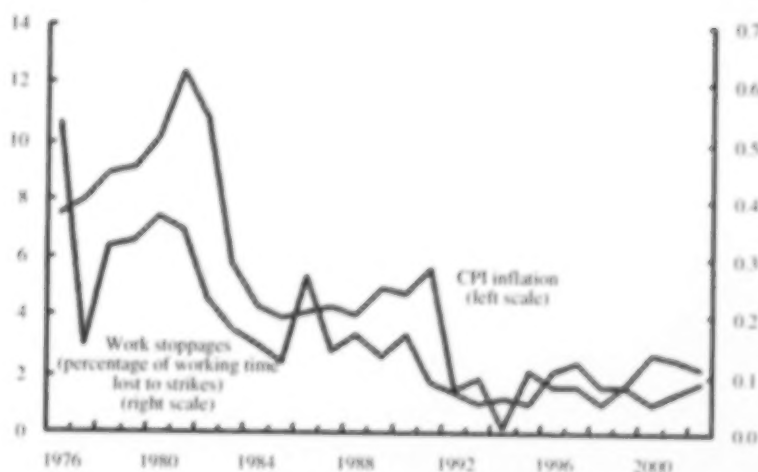
Howitt also argued that with low, stable, and predictable inflation there would be less uncertainty about real and relative wages and hence less need for labour confrontations, resulting in lower person-day loss to strikes. This conclusion also seems to be corroborated by Canadian evidence (Figure 2).

Conclusions

The objective of this conference was to examine the current state of knowledge on critically important issues for the conduct of monetary policy. We have learned a lot about the considerable conceptual insights from the latest generation of general-equilibrium models, and we confronted a number of empirical issues. If there is one lesson that I hope we all take from this conference, it is the importance of allowing for regime changes in the conduct of monetary policy when doing empirical investigation of the behaviour of inflation.

As to where we go from here, I believe that Beverley Lapham and Gregor Smith have pointed the way. We need more microeconomic analyses of price-setting behaviour. We also require a better understanding of the decisions along the distribution chain, of the reasons for local currency pricing or pricing to market, and of the differences by industry. With that in mind, the Bank's regional offices are undertaking a survey of firms, much in the spirit of Blinder et al. (1998), and will be asking real-world price-setters how prices are set and in which currency.

Figure 2
Inflation and percentage of person days
lost because of strike activity



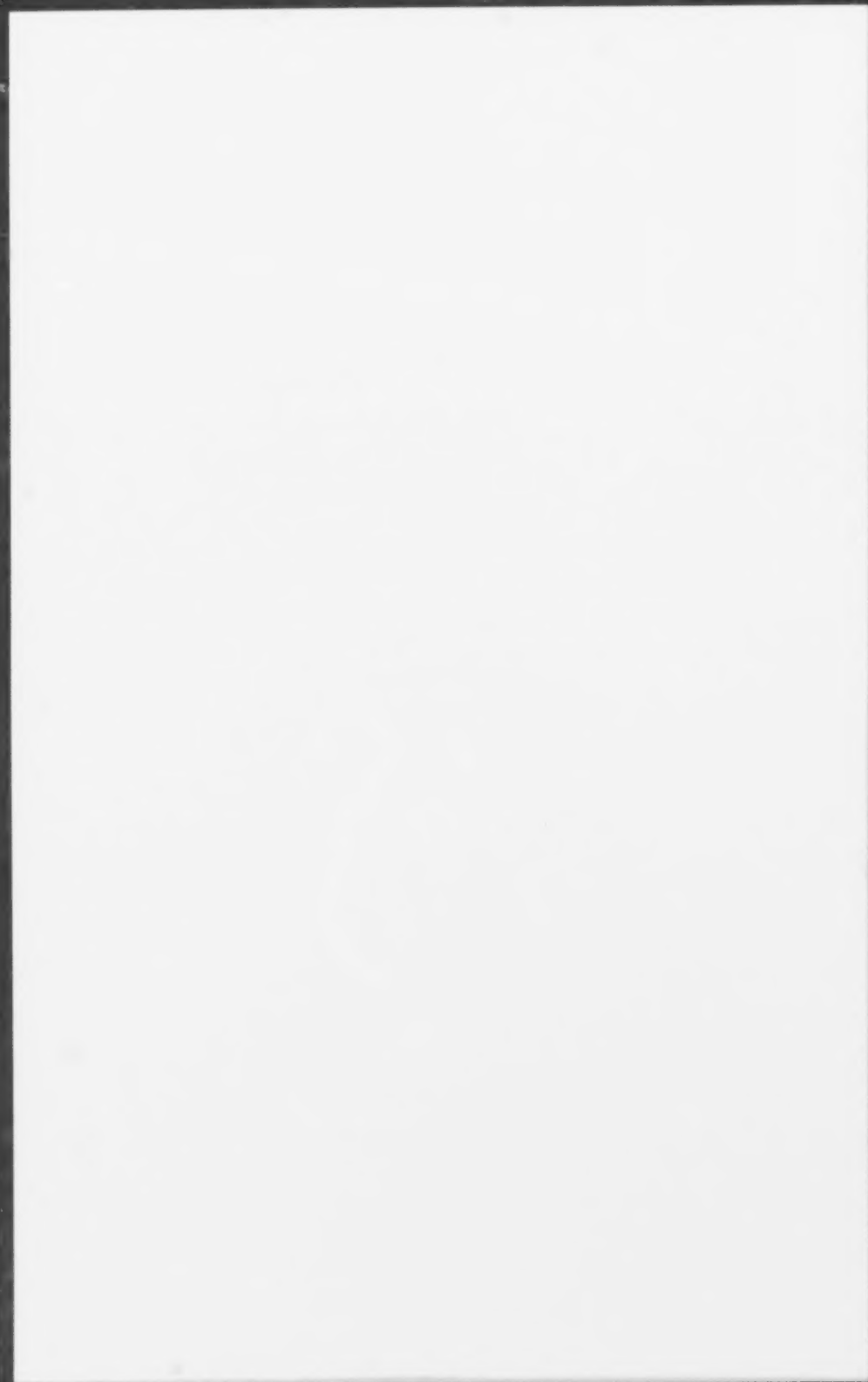
Finally, a review of large empirical multi-country models could be an instructive complement to David Bowman and Brian Doyle's excellent survey of the literature.

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